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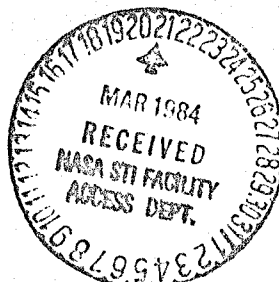
# Fundamental Remote Sensing Science Research Program Part I: Status Report of the Scene Radiation and Atmospheric Effects Characterization Project

R. E. Murphy and D. W. Deering

MARCH 1984

National Aeronautics and  
Space Administration

Goddard Space Flight Center  
Greenbelt, Maryland 20771



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FUNDAMENTAL REMOTE SENSING SCIENCE

RESEARCH PROGRAM PART I:

STATUS REPORT OF THE SCENE RADIATION  
AND ATMOSPHERIC EFFECTS CHARACTERIZATION PROJECT

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## PREFACE

With the continuing technological evolution of remote sensing from space, it is evident that we benefit from the technology only to the degree to which we understand the information captured in the remotely sensed image itself. Images of the Earth acquired from space vary according to the scene properties they portray. Images are dependent on the natural variance in radiance from the Earth's surface, the effect of the atmosphere on the transfer of radiation, and the measurement capability of the sensor. What we can learn from orbital images depends on our ability to understand the transfer of electromagnetic energy from the Earth's crust through the atmosphere, and the absorption, emittance, and reflectance characteristics of both organic and inorganic materials of the Earth's surface. We must also be able to accurately register an orbital image, and the information contained therein, to its true location on the Earth's surface. Thus, with an understanding of energy transfer from the target to the sensor and accurate procedures for geographical registration, we have the spectral and spatial attributes of an image that will allow us to infer the maximum amount of information from a scene. Some techniques that generate information from an image may be fundamental and generic in their application to the characterization of scene properties in all images. The development of generic techniques to advance our understanding of remotely sensed images represents an emerging, highly sophisticated science.

The National Aeronautics and Space Administration, as an established sponsor of remote sensing technology research, has embarked on a specialized and continuing research program in fundamental remote sensing science. After an evaluation of major research needs, the agency has defined two significant projects:

1. Scene radiation and atmospheric effects characterization (SRAEC), and
2. Mathematical pattern recognition and image analysis (MPRIA).

In 1981, NASA solicited research proposals related to the two projects from both the NASA and external science community. After a competitive evaluation of submitted proposals, NASA selected approximately 35 investigations and awarded funding in 1982.

The investigations of both research projects strive to improve our understanding of scene properties. The two projects can be differentiated by the basic approach underlying each. The SRAEC project seeks to understand the fundamental relationship of energy interactions between the sensor and the surface target, including the effect of the atmosphere, to construct theoretical models predicting the radiance of the Earth's surface. Model inversions can then be applied to interpret the information contained in a space-acquired image of measured radiance. Conversely, the MPRIA project seeks to develop analytical techniques that group the radiance values contained in an image on a statistical basis to infer the properties of the scene, ultimately to understand the condition of the Earth's surface. An important component of MPRIA lies in the development of technique for image georegistration and recognition of texture. The information associated with spatial patterns, or texture, of radiance in an image may contribute substantially to the inference of scene properties.



The Fundamental Remote Sensing Science Research Program supports the long-term goals of NASA in two significant ways. First, the techniques developed through the program enhance our ability to learn more about the physical and biological processes of our planet from space acquired data. Second, the results of the investigations contribute to a base of scientific understanding needed to support the planning of new and effective sensors and flight programs.

This report is submitted to describe the Fundamental Remote Sensing Science Research Program and the progress made since its initiation approximately two years ago. The report is represented in two parts. Part I provides the status of the Scene Radiation and Atmospheric Effects Characterization Project, primarily reflecting research results presented at the Second Annual Workshop for Investigators held at Colorado State University in Fort Collins, January 9-11, 1984. Part II provides the status of the Mathematical Pattern Recognition and Image Analysis Project, which consists of current results and information summarized from the proceedings of the NASA Symposium on Mathematical Pattern Recognition and Image Analysis held June 1-3, 1983.

By the end of 1984, NASA will announce a new opportunity for research in this continuing program. Topics for the solicitation of research will be defined in the months ahead and will be based on the outgrowth of results of present investigations and the fundamental research needs of other NASA programs that incorporate remote sensing for Earth observations.

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Guseman, Jr., L. F. 1983. Proceedings of the NASA Symposium on Mathematical Pattern Recognition and Image Analysis, June 1-3, 1983, Johnson Space Center, Houston, Texas. Contract NAS9-16664. Texas A&M University, Department of Mathematics, College Station, Texas.

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FUNDAMENTAL REMOTE SENSING SCIENCE RESEARCH PROGRAM  
PART I: STATUS REPORT OF THE  
SCENE RADIATION AND ATMOSPHERIC EFFECTS CHARACTERIZATION PROJECT

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I. SRAEC PROJECT OBJECTIVES

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I.A. NASA FUNDAMENTAL REMOTE SENSING SCIENCE RESEARCH PROGRAM

NASA's research programs during the past decade that have addressed the use of remotely sensed measurements of the earth's surface have been typically of an applied nature. The satellite sensor designs of the 1970's were based largely on the laboratory, field and aircraft multispectral observations made in the 1960's, with limited understanding of cause-and-effect relationships between scene attributes and observed scene radiation. Similarly, the machine techniques for data analysis and information extraction have been based largely on pattern recognition procedures, which ignore cause-and-effect as applied to satellite data labeling. In short, the development of rapid, empirical approaches to data interpretation has taken precedence over the development of a full scientific understanding of the earth-atmosphere scene radiation complex.

The importance of remote, synoptic measurements of the earth's surface and atmosphere has been clearly demonstrated, however, and the need and desire to fully utilize these powerful remote sensing measurements has reached the point where empirical techniques are no longer sufficient. The complex electromagnetic energy interactions among the various components of earth surface scenes and the atmosphere must be understood if further progress is to be made in remote sensing technology. Further advancement in both components and systems, hardware and software, and user confidence and use requires increased understanding of the characteristics of scene radiation and atmospheric effects at visible, infrared and microwave wavelengths.

In order to meet this need for a more fundamental knowledge or understanding of earth radiation for supporting future space technology developments and applications research, NASA has established the Fundamental Remote Sensing Science Research Program within the Land Processes Branch of the Earth Science and Applications Division at NASA Headquarters. This fundamental research

program currently contains two elements including (1) Scene Radiation and Atmospheric Effects Characterization, which this status report addresses, and (2) Mathematical Pattern Recognition and Image Analysis.

The Fundamental Remote Sensing Science Research Program provides a dynamic scientific base that will be continually broadened and strengthened and from which future applied research and development can draw support. The Scene Radiation and Atmospheric Effects Characterization (SRAEC) Project element is being conducted to improve our understanding of the energy emitted or reflected from an earth surface target, through the intervening atmosphere as measured by a remote sensing system.

## I.B. RELATIONSHIP OF SRAEC TO NASA OBJECTIVES

The Fundamental Remote Sensing Science Research Program's Scene Radiation and Atmospheric Effects Characterization Project is of a complementary nature to other NASA programs, but particularly focused upon providing the essential framework for future applied earth resources research projects. The study of the characteristics of radiant energy interactions with the earth atmosphere and earth surface elements is of fundamental significance to the general physical science community, but also has potential application in the NASA planetary programs for the interpretation of planet surface features from orbiting space probes.

NASA is chartered to expand human knowledge of phenomena in the atmosphere and to pursue practical benefits that can be gained from aeronautical and space activities. With man's exponentially increasing impact on both the earth's surface and the atmosphere, the need to measure and monitor these anthropogenically induced processes has become apparent to not only the scientific community but also the educated public as well. Thus, a significant practical benefit to all of human-kind and other earth life forms will accrue from an improved capability to globally sense and interpret earth surface features and changes through the atmosphere from space platforms.

A new programmatic theme called Global Habitability, has thus developed within the Earth Science and Applications Division of the Office of Space Science and Applications. The overall objective is to investigate long-term physical, chemical, and biological trends and changes in the earth's environment, including its atmosphere, land masses, and oceans. The program is intended to specifically investigate the effects of natural and human activities on the earth's environment by measuring and modeling important physical, chemical, and biological processes, and their interactions. The methodology involves the acquisition and analysis

of space and suborbital observations, land-based measurements, modeling and laboratory research, as well as supporting data management technologies over a ten-year or longer period of time. The product of the SRAEC project will be an improved understanding of the physical radiant energy interaction (remote sensing) processes through measurements and modeling that will ultimately enable the proper specification of earth observing space sensor systems and the measurement and modeling of the important physical, chemical, and biological processes and their interactions.



## I.C. SRAEC RESEARCH ISSUES AND INITIAL FOCUS

NASA organized and conducted a study during fiscal year 1980 to identify the fundamental research needs for future applications research in aerospace remote sensing. Through a series of ongoing workshops involving leading scientists from universities, industry and government, the Scene Radiation and Atmospheric Effects Characterization working group identified specific priority research issues. These research issues, summarized briefly below, helped define the basis for a long term SRAEC fundamental remote sensing research project.

The scene radiation and atmospheric effects research can be generically structured into four types of activities including observation of phenomena, empirical characterization, analytical modeling, and scene radiation analysis and synthesis. The first three activities are the means by which the goal of scene radiation analysis and synthesis is achieved, and thus are considered priority activities during the early phases of the current project. Scene radiation analysis refers to the extraction of information describing the biogeophysical attributes of the scene from the spectral, spatial, and temporal radiance characteristics of the scene including the atmosphere. It is the process by which remotely sensed data are examined for factors which give rise to distinguishing characteristics between object scene classes or between levels of attributes within classes. Scene radiation synthesis is the generation of realistic spectral, spatial, and temporal radiance values for a scene with a given set of biogeophysical attributes and atmospheric conditions. In the past, most of the radiation characteristics of scene elements used for scene radiation synthesis were based on empirical characterizations. The addition of analytic models from the SRAEC research will strengthen this activity and simplify data base structure and memory storage.

The SRAEC working group concluded that despite the differences in instrumentation and research techniques and approaches used by experimenters working in the various electromagnetic frequency regimes, there is a set of common needs that exists for all subcategories. These common needs or "themes," which the SRAEC project will address, include:

- 1) A need for the systematic evaluation of existing scene models (e.g. plant canopy models) including validation, verification, and sensitivity analysis.
- 2) A need to extend the existing models to heterogeneous media.
- 3) A need to develop parameter estimation requirements, specifically for spatially distributed scenes.
- 4) The overriding necessity to relate electromagnetic parameters to the classical biophysical descriptors.
- 5) The lack of knowledge about the statistical distribution of the spatial and temporal variability of the underlying parameters.
- 6) The need to develop stronger links between experimental programs and theoretical work.
- 7) The dichotomy in problem conceptualization; that is, on the one hand, given a knowledge of the underlying parameters and appropriate mathematical descriptions, being able to predict response or conversely, given the measured response being able to infer scene attributes or to develop correction procedures.

More specifically, research to be conducted within the SRAEC program is being focused on the development of empirical characterizations and mathematical process models which relate the electromagnetic (EM) energy reflected or emitted from a scene to scene characteristics. These parameters similarly need to be related to the biophysical parameters of interest. For example, the EM characteristics of vegetation canopies might be modeled in terms of the reflectance, transmittance, and absorptance properties of the leaves and stems and in terms of the geometric orientation and distribution of the parts over the space occupied by the vegetation. A second model might then be used to relate plant moisture deficiency levels to the EM properties of the canopy

parts and geometry. Such models could, therefore, support an analysis of the effects of different moisture deficiency levels on the EM radiation properties.

Improved theoretical approaches to the study of the radiation characteristics of various types of earth resources are needed, particularly for renewable resources. There are significant limitations in the relatively few models that currently exist for the optical and microwave regions of the spectrum. Similarly empirical characterizations are limited and generally suffer from insufficient controls or lack of supporting data. The available models are constructed on assumptions that confine their use to restricted situations. Consequently, priority is being given to the development of improved theoretical and empirical approaches to the study of scene radiation.

Observational studies are needed to empirically characterize the bidirectional reflectance distribution functions, thermal properties, and microwave scattering characteristics of important earth resource classes (e.g., various crop canopies, forest canopies, snow, soil types). The spatial and temporal variations of biological and physical attributes of these classes must also be observed in order to characterize the effects of these variations on the reflected and emitted radiation. The spatial distribution of atmospheric scattering and absorbing components also requires observation and characterization to improve current models which assume atmospheric uniformity in the horizontal dimension. There is a significant lack of understanding of the distribution of the atmospheric scattering and absorption elements over geographic regions of 25 to 75 square kilometers and larger.

The empirical observations and characterizations should lead to the formulation of mathematical process models which relate reflected and emitted radiation to scene attributes. The models must be based on sound biological and physical principles which take into account the observed biological and

physical attributes of the earth resource targets and the atmosphere. Models are needed for both individual resource classes and scenes containing a mixture of classes. Models are also needed to describe atmospheric variations over large areas. It is anticipated that these atmospheric models will be developed through research that is coordinated with empirical characterizations of natural terrain materials and planned in a design that will identify the natural variations of important atmospheric conditions at wavebands of interest over large areas. The applicability of existing atmospheric radiation models to deal with such variations could then be assessed and, if necessary, existing models could be modified or new ones developed to analyze important atmospheric effects.

Since fundamental research is designed to support applied research activities the SRAEC working group considered that it may be useful to address general categories of questions which are needed inputs to applied research. These general questions provided a practical framework for prioritizing proposed fundamental research and included:

- 1) What are the spectral properties and differences in properties between various vegetative canopies as a function of relative differences in phenology? Which features of these canopies give rise to these spectral differences?
- 2) To what degree are spectral differences in canopies obscured by background effects such as variation in atmospheric haze and aerosols, soil background variations and variations in canopy density induced by varietal or ecotypical differences and cultural practices?
- 3) How are the reflective and emissive properties of the canopy modified as a function of canopy conditions as influenced by drought stress, flooding, disease and insect damage?

Thus, research investigations which will develop improved empirical and theoretical approaches to the quantitative characterization of electromagnetic radiation reflected and emitted from renewable resource scenes are being supported, as well as studies which will improve quantitative descriptions of

atmospheric scattering and absorption. The SRAEC studies that were initially selected and funded are described in Section II and will contribute to the capability for scene analysis and synthesis and will extend and strengthen the fundamental basis for applied remote sensing research.

Areas of research needed that are not currently possible due to funding constraints include the theoretical integration of all wavelength regime (optical-reflective, microwave, thermal) modeling and the attendant coupled measurements program to support this activity. Thermal regime research is needed. Observational (measurements) support programs are essentially lacking, especially for non-agricultural areas. Atmospheric measurements programs are needed that require support at a more sophisticated funding level. Instrument development is significantly lacking for fundamental research needs. It is important to note that the early fundamental research activities have been able to piggyback to a considerable extent on observational studies previously supported by other major NASA programs (e.g., LACIE/AgRISTARS) that have "dried up." These current and future fundamental remote sensing research studies will suffer significantly unless a strong observational base can be reestablished within the SRAEC project.

## II. SRAEC INVESTIGATIONS AND WORKSHOPS

## II.A. Scope of Current Studies

Proposals from organizations outside NASA were officially solicited on July 27, 1981 and peer reviewed during December 8-11, 1981. The selected investigations are grouped into three categories and given by title, principal investigators and institutional affiliation in Table II-1. The geographic locations of these investigators are shown in Figure II-1 (see also Appendix A). The proposed research and funding were subsequently negotiated between the Science Manager and Principal Investigators to conform to the budgetary constraints. Each of the initial investigations cover two to three years of activity. The sixteen investigations can be logically grouped into three categories: 1) scene radiation studies at visible and infrared wavelengths, 2) scene radiation studies at microwave wavelengths, and 3) atmospheric effects studies.

Seven investigations have as their common theme the understanding of visible and infrared radiation interaction with plant canopies. Heavy emphasis is placed on the theoretical development of multi-dimensional canopy reflectance models and on empirical characterizations of the bidirectional reflectance distribution function of various cover types and conditions. Individual, intensive laboratory and field measurement programs that relate biophysical variables to reflectance parameters complement the various modeling activities.

One of the seven "canopy" studies (Diner) has emphasized atmospheric effects during the first 18 months and thus has been grouped with the atmospheric investigations in the remainder of this report. Three other investigators have the atmosphere and its effects on earth resources remote sensing as their primary focus. Emphasis is on theoretical causes of the atmospheric effects, the magnitude and variations of the atmospheric effects, and correction algorithms to account for the effects. Some field experiments to complement

Table II-1. SRAEC Project Principal Investigators, Institutional Affiliations,  
and Research Topics According to Three General Subject Categories.

PRINCIPAL INVESTIGATOR	INSTITUTION	RESEARCH TOPIC
SCENE RADIATION STUDIES:		
<u>Visible and Infrared Wavelengths</u>		
James Smith	Colorado State Univ.	Reflectance Modeling [Multidimensional Radiative Transfer Model Development and Extension]
John Norman	Univ. of Nebraska	Bidirectional Reflectance Modeling of Non-Homogeneous Plant Canopies
Dan Kimes	NASA/Goddard Space Flight Center	Comprehensive Understanding of Vegetated Scene Radiance Relationships
Vern Vanderbilt	Purdue Univ.	Measurement and Modeling of the Optical Scattering Properties of Crop Canopies
Alan Strahler	Hunter College	Reflectance Model [A Geometric Model for Heterogeneous Canopies of Partial Cover]
Gautam Badhwar	NASA/Johnson Space Center	The Relation Between Crop Growth and Spectral Reflectance Parameters
Dave Diner	NASA/Jet Propulsion Laboratory	Bidirectional Spectral Reflectance of Earth Resources: Influence of Scene Complexity and Atmospheric Effects on Remote Sensing
<u>Microwave Wavelengths</u>		
Adrian Fung	Univ. of Kansas	Scattering Models in the Microwave Regime
Jin Au Kong	Massachusetts Inst. of Tech.	Remote Sensing of Earth Terrain



Table II-1 (cont'd). SRAEC Project Principal Investigators, Institutional Affiliations, and Research Topics according to the General Subject Categories.

PRINCIPAL INVESTIGATOR	INSTITUTION	RESEARCH TOPIC
<u>Microwave Wavelengths</u>		
Roger Lang	Geo. Washington Univ.	Discrete Random Media Techniques for Microwave Modeling of Vegetated Terrain
Fawwaz Ulaby	Univ. of Kansas	Measuring and Modeling of the Dielectric Properties and Attenuation of Vegetation
R. K. Moore	Univ. of Kansas	Measuring and Modeling of the Dielectric Properties and Attenuation of Vegetation
Jack Paris	NASA/Jet Propulsion Laboratory	Microwave Backscattering Properties of Crops
<u>Atmospheric Effects Studies</u>		
Robert Fraser	NASA/Goddard Space Flight Center	Atmospheric Effect on Remote Sensing of the Earth's Surface
William Pearce	EG&G Washington Anal. Services Center	The Characterization of Surface Reflectance Variation Effects of Remote Sensing
Siegfried Gerstl	Los Alamos Nat'l Lab.	Multidimensional Modeling of Atmospheric Effects and Surface Heterogeneities on Remote Sensing



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Figure II-1. Geographic locations of the SRAEC principal investigators.

the model development are being conducted.

Six investigations are concerned with the microwave (active and passive) remote sensing potentialities. Emphasis is placed on measuring and understanding the backscatter properties of specific scene elements and the physical causes for these scattering properties. Scattering and emission models are also being developed and tested for vegetation, soil, and snow cover.

Further details of the goals, objectives and accomplishments for the individual investigations are provided in Section III.

## II.B. FIRST ANNUAL WORKSHOP

The first meeting of the SRAEC principal investigators was held January 5-7, 1983 at the University of Colorado in Boulder as a part of the National Radio Science Meeting. The SRAEC papers were presented in two sessions entitled "Optical and Microwave Studies of Vegetative Surfaces-I: Theoretical Investigation" and "... II: Observational Investigations". These sessions were chaired by Jin A. Kong and Daniel S. Kimes, respectively.

Most of the SRAEC investigators had been under contract for only approximately six months by the time of this meeting, and consequently many of the investigator reports concerned the theoretical approaches being taken to address the problems under study and analysis of previously acquired data.

The principal objective of this first meeting, however, was to bring this diverse group of investigators together to learn about the different SRAEC studies underway, share ideas, and foster syngergism and possible collaborative efforts. It was deemed particularly important to begin developing better communication bridges between the three major research topical areas; optical, microwave and atmosphere.

Following the meeting Mike Calabrese (at that time the NASA Headquarters Renewable Resources Program Manager responsible for the SRAEC and MPRIA projects) wrote that the SRAEC Project "serves as an excellent forum to discuss and articulate the merging of visible, IR, and microwave theoretical and experimental techniques. The investigators are beginning to show an awareness of this merger. I recommend that the upcoming workshop address this merger by sharing terminology and making tutorial presentations in their respective areas of expertise. The research could provide the 'tools' to conduct 'multispectral' science experiments on future shuttle missions."

## II.C. SECOND ANNUAL WORKSHOP

The second meeting of the SRAEC principal investigators was held January 9-11, 1984 at Colorado State University in Fort Collins. The National Radio Science Meeting was held in nearby Boulder during the latter part of the same week, thus enabling a concentrated SRAEC workshop and yet allowing those participating in the Radio Science meetings to conveniently attend both. The Fort Collins meeting was hosted by Jim Smith and the Laboratory for Applications of Computers in Forestry at CSU. Workshop participants are listed in Appendix B.

The first half of the meeting consisted primarily of tutorial presentations on terms, measurements and concepts in the three principal SRAEC disciplines--optical regime, microwave regime and atmosphere (see Appendix C--Second Workshop Agenda). The second half of the meeting was devoted to the principal investigator results presentations. In addition, Dick Heydorn, Science Manager for the Mathematical Pattern Recognition and Image Analysis (MPRIA) Project gave an overview presentation on the MPRIA studies and two of the MPRIA investigators presented their individual investigations. The reaction to including the MPRIA presentations in the workshop was excellent.

The meeting was highly interactive and provided a good mechanism for cross-fertilization between disciplines. It was originally planned to separate into discipline focused splinter groups for discussion of research issues, but the overwhelming consensus among the principal investigators was to stay together and share ideas on the important research topics and the possibilities for a joint experiment to support all of the modeling efforts. Time constraints did not allow a full development of these ideas and it was concluded that a further workshop in a few months was highly desirable. The theoreticians expressed an interest in developing closer contacts with the experimentalists, and the

individual investigator reports proved to draw more discussion than time would permit at this meeting.

The NASA Headquarters Remote Sensing Science Program Manager's comments on the meeting are given in Appendix D. The results presented at this meeting provide the basis for this status report and are presented as a project overview (Section III A), as individual study abstracts (Section III B), and as more detailed and graphically highlighted synopses (Section III C) in the following section of this report.

One strategic outfall from the annual meeting and workshop of the SRAEC principal investigators was an updating of the list of publications (Section III D) that has resulted from this fundamental research effort over the past 1 1/2 - 2 years. SRAEC scientists have had significant progress and accomplishments that have resulted in the 35 journal articles--19 currently published and 16 in press. Seven additional papers have been submitted and are in review.

### III. SRAEC RESEARCH RESULTS

### III.A. SRAEC PROJECT PROGRESS AND ACCOMPLISHMENTS

SRAEC project investigators have made great strides in the theoretical development of plant canopy and whole scene modeling. New approaches to radiative transfer calculations have been formulated and validated. Greater understanding of the bidirectional reflectance of subcanopy elements and their role in canopy anisotropic response has been gained, and variable surface reflectance interaction with the varying atmosphere is becoming a tractable problem. Important measurements of dielectric properties of vegetation are being made, and improvements have been made in the vigor of microwave vegetation models. This section of the report briefly summarizes some of the accomplishments according to the three general discipline categories: scene radiation studies in the visible and infrared regime, scene radiation studies in the microwave regime and atmospheric effects studies. More detailed summaries are given in Sections III.B. and III.C.

#### Optical-Reflective Regime

The central theme of the scene radiation studies in the optical-reflective regime is to gain a greater understanding of the bidirectional reflectance properties of subcanopy elements (e.g. individual leaves), whole plant canopies and background surfaces and to develop more accurate models of heterogeneous canopies or scenes. Most of the new data acquisitions are rather unique, as almost no data exists in the literature on the bidirectional reflectance distribution functions (BRDFs) of subcanopy elements, canopies, and background soils. New technique and analysis procedure development are becoming necessary activities for these studies.

Subcanopy element and soil measurement data analyses are revealing that current canopy models must be incorrect in that they 1) use the wrong leaf



spectral (reflectance and transmission) properties due to individual leaf anisotropy (Norman), polarization (Vanderbilt) and the significant leaf specular contribution to total reflectance (Vanderbilt), 2) use normal inclination leaf reflectance rather than real leaf orientation characteristics that give rise to anisotropy of reflectance (Kimes, Norman), and 3) assume lambertian soil background reflectances which are invalid (Kimes, Norman, Smith). Attempts are being made to incorporate this new knowledge into the various canopy models and some early success has been achieved (Kimes, Smith).

Current evidence from model results and validation measurements is that two primary mechanisms cause the directional scattering of complete, homogeneous canopies. The first is caused by shadowing gradients and view projection gradients within the canopy and the second is the primary directional scattering of the leaves due to leaf orientation, source direction, and leaf reflectance and transmittance values (Kimes). Sparse or heterogeneous canopies are more difficult to interpret but have a strong dependence on the soil background. Models may in fact have difficulty distinguishing between rough soils and sparse canopies without combining wavelength and angular information together in a single, complex formulation (Norman).

The shadowing problem is being studied through a modeling and field study at a larger "scene" scale for discontinuous conifer forest canopies, wherein the trees are considered as collections of conical forms that are illuminated at an angle and cast shadows on a contrasting background (Strahler). Currently, an earlier invertible geometric model has been successfully modified to correct for the reduction in shadow and canopy area that occurs when shadows fall on crowns or tree crowns intersect (overlap).

In addition to the aforementioned studies that attempt to model canopies on the spatial or three-dimensional scales, one investigation is examining

canopy reflectance on the temporal scale for ascertaining vegetation types and characteristics from spectral transform trajectories (Badhwar). A mathematical technique that maximizes the sensitivity of spectral transformation to Leaf Area Index and simultaneously minimizes the sensitivity to all other variables has been formulated and successfully tested for two canopy types.

#### Microwave Regime

Somewhat analogous to the subcanopy element reflectance measurements in the optical-reflective regime are the microwave dielectric properties and backscatter sources measurements of vegetation material being performed in the microwave/radar regime studies. The amount of data acquired thus far in only one of these studies is at least an order of magnitude greater in volume than the total cumulative amount of data reported in the literature to date. Heavy emphasis during the first year and one half has been on developing new techniques for laboratory and field measurements.

Field measurements with a 10 GHz radar system showed that the portion of a plant canopy that is the primary source of the backscatter differs for different plant canopy types and conditions (Moore). Typically, the top cluster of leaves in green plant canopies are the main backscattering source for 30° incidence angles (e.g., corn, milo, soybean). However, upon maturation either the lower portions of the stalks or stems or the seed head are the dominant sources. For vertical incidence angles greater penetration into soybean canopies occurred such that 14 dB of a total 17 dB loss was due to the lower portion of the plant where the stems are located. For corn, however, the top leaves were still the dominant backscatter source (22 dB total loss).

These results are supported in a single-scattering/canopy structure model validation experiment using corn and wheat measurements. The use of explicit leaf biophysical parameters (and the ignoring of stalk and fruit parameters) in

the model led to a significant improvement in the goodness of fit of the model predictions to the observations [for example, at 17 GHz with VV polarization, the  $r^2$  increased from 0.79 to 0.93], and SIGMA for an average corn leaf was found to have an excellent ( $r^2$  of 0.97) power law relation to average green leaf area. Such a dramatic increase in the fit of the model will allow scientists to extract desired canopy parameters such as leaf area index and areal leaf water content from radar backscattering measurements and will pave the way for better empirical experiments to investigate the fundamental causes of backscatter by vegetation (Paris).

In another study dielectric measurements at three microwave wavelengths were made of the liquid included in vegetation material after extraction by mechanical means (Ulaby). These measurements explained the heretofore unexpected frequency behavior of the dielectric constant of the vegetation-water mixture. It has always been assumed in the literature that the attenuation coefficient of vegetation increases with increasing frequency because its dielectric constant is proportional to that of pure water. It was found in this investigation that the water contained in the vegetation materials has a salinity of 10 to 15%, which results in a vegetation dielectric constant that is about 15 times larger than that previously expected at 1 GHz. This means that the propagation loss is more than an order of magnitude greater than had previously been assumed. These results are expected to have a significant effect on the future development of models of emission and scattering from vegetation canopies (Ulaby).

Three of the microwave investigations have been more strongly oriented to theoretical model development. In the past, rough surface scattering and volume scattering were treated independently as two separate fields of study. One of the modeling investigations combines the techniques in the two areas using the radiative transfer method (incoherent transport theory) to provide a more

realistic terrain scattering model and permits the study of the interaction between surface and volume scattering (Fung). Another uses both coherent and incoherent techniques wherein vegetation is modeled by discrete scatterers such as leaves, stems, branches and trunks, which have been replaced by lossy dielectric disks and cylinders. Rough surfaces are represented by their mean and spectral characteristics and average scattered power is then calculated by employing discrete random media methodology, such as the distorted Born approximation or transport theory (Lang). The third study has developed an anisotropic random media model together with a discrete scatterer model with nonspherical particles for vegetation fields due to the strong azimuthal dependence in the observed data. However, the investigator has also developed numerous theoretical models that are designed for active and passive remote sensing of plowed fields and snow fields as well as atmospheric precipitation (Kong).

From rough surface/volume scattering model investigations, rough surface scattering was found to be important at near vertical observations (enhances cross-polarized scattering) and volume scattering from layer inhomogeneities was found to dominate scattering (like and cross polarized) at large incidence angles (Fung). The discrete scatterers model calculations showed that leaves dominated the backscatter return for HH polarization while stems were important for VV polarized returns at large angle of incidence (Lang).

In a companion modeling effort it was found that scattering measurements are more sensitive to soil moisture changes than emission measurements because while both types of measurements lose sensitivity to soil moisture because of the vegetation layer, the loss is greater for passive than active measurements (Fung).

### Atmospheric Effects

The atmospheric effects studies at the present time are primarily theoretical modeling studies designed to determine the principal causes and magnitude of the atmospheric effects on the remote sensing of earth surface features. The coupling of atmosphere and canopy reflectance models is beginning to evolve. Four of the SRAEC investigations have emphasized the atmospheric transport medium. Considerable effort during the early phases of these studies has involved the development and modification of radiative transfer codes for remote sensing applications or to handle non-uniform and non-lambertian surfaces and to improve computational efficiencies.

Considerable interest in these atmosphere studies has centered on the nature and magnitude of the atmospheric "point-spread" function or adjacency effect. The influence of atmospheric scattering has been found to extend several kilometers from each surface point (Diner, Fraser, Pearce). A laboratory simulation experiment was conducted to verify the existence of the adjacency effect (the effect of a bright field on the radiance detected above a dark field) and was used to test 3-D radiative transfer models (Fraser). The adjacency effect was shown to reduce the separability between surface classes (in addition to its effect on spatial resolution and classification accuracy). This new effect is present when the field size is of the order of the atmospheric scale height (Fraser).

Theoretical computations that compare cases in which increasing amounts of aerosol are shifted in the stratosphere, while maintaining a constant optical depth, show that the effect on the spread function is to scale it linearly as would be expected from a single scattering model (Pearce). The aerosol absorption effect was found to be stronger for high than low surface reflectances, but the aerosol optical thickness was dominant for small surface reflectances (Fraser).

Remote sensing of contrast, such as with the Vegetation Index, is only weakly affected by aerosol absorption but is affected by aerosol scattering (Fraser, see also Gerstl).

Preliminary investigation of anisotropic leaf scattering characteristics appear to produce only negligible effects on satellite measured data above the atmosphere. Additionally, non-Lambertian and specular surface reflectance characteristics (BRDF) seem to affect satellite measurements at nadir only insignificantly, but can make large differences for off-nadir observations (Gerstl).

One encouraging new technique development, based on the different spatial characters of radiation directly and diffusely transmitted to space, may enable determining atmospheric optical depth from an orbiting spacecraft (Diner).

III.B. INDIVIDUAL STUDY RESULTS SUMMARIES

(ABSTRACTS)

### III.B.1. SCENE RADIATION STUDIES--OPTICAL REGIME

- J. Smith - Reflectance Modeling [Multidimensional Radiative Transfer Model Development and Extension]
- J. Norman - Bidirectional Reflectance Modeling of Non-Homogeneous Plant Canopies
- D. Kimes - Comprehensive Understanding of Vegetated Scene Radiance Relationships
- V. Vanderbilt - Measurement and Modeling of the Optical Scattering Properties of Crop Canopies
- A. Strahler - Reflectance Model [A Geometric Model for Heterogenous Canopies of Partial Cover]
- G. Badhwar - The Relation Between Crop Growth and Spectral Reflectance Parameters
- D. Diner - (see III.B.3)



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*Smith, K. Cooper and M. Randolph*  
REFLECTANCE MODELING

J. Smith, K. Cooper and M. Randolph  
Colo. St. Univ.

We completed our classical description of the one-dimensional radiative transfer treatment of vegetation canopies and tested the results against measured prairie (blue grama) and agricultural canopies (soybean). Our phase functions are calculated in terms of directly measurable biophysical characteristics of the canopy medium. While the phase functions tend to exhibit backscattering anisotropy, their exact behavior is somewhat more complex and wavelength dependent. Comparisons with classical Rayleigh and Henyey-Greenstein formulations are given. A main advantage of this formulation is its compatibility with other atmospheric investigators in the program. Several areas for extension are suggested by the work of Gerstl, Norman and Kimes involving individual leaf optical anisotropy and leaf azimuth orientation.

A Monte Carlo model has been developed that treats soil surfaces with large periodic variations in three dimensions. A photon-ray tracing technique is used. Currently, the rough soil surface is described by analytic functions and appropriate geometric calculations performed. A bidirectional reflectance distribution function is calculated and, hence, available for other atmospheric or canopy reflectance models as a lower boundary condition. The authors have used this technique together with their adding model to calculate several cases where Lambertian leaves possessing anisotropic leaf angle distributions yield non-Lambertian reflectance, similar behavior is exhibited for our simulated soil surfaces.

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BIDIRECTIONAL REFLECTANCE MODELING OF NON-HOMOGENEOUS PLANT CANOPIES

J. M.  
J. Norman  
U. of Nebr.

*W. J. R. R. R. R. R.*

The main objective of this research is to develop a three-dimensional model to predict canopy, bidirectional reflectance for heterogenous plant stands using incident radiation and canopy structural descriptions as inputs. During the first year we have developed utility programs to cope with the complex output from the 3-dimensional model and begun coding of the 3-D model. In addition we have attempted to define leaf and soil properties, which are appropriate to the mode, by measuring leaf and soil bidirectional reflectance distribution functions; since almost no data exist on these distributions. In the process we have come to believe that most models probably are using the wrong leaf spectral properties, and that off-nadir reflectance measurements are difficult to make because of non-Lambertian properties of reference surfaces. Also, in the visible wavebands, rough soil may not be distinguishable from canopies when viewed from above.

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COMPREHENSIVE UNDERSTANDING FOR VEGETATED SCENE RADIANCE RELATIONSHIPS

Vol 5.  
D. Kimes and D. Deering  
NASA/GSFC

The overall objective of the three-year study is to improve our fundamental understanding of the dynamics of directional scattering properties of vegetation canopies through analysis of field data and model simulation data. The specific first and second year objectives were to (1) collect directional reflectance data covering the entire exitance hemisphere for several common vegetation canopies with various geometric structure (both homogeneous and row crop structures), (2) develop a scene radiation model with a general mathematical framework which will treat 3-D variability in heterogeneous scenes and account for 3-D radiant interactions within the scene and (2) expand 3-D model to include anisotropic scattering algorithms at the "cell" level, (3) conduct initial validation of model on row crop data sets, and (4) test and expand proposed physical scattering mechanisms involved in reflectance distribution dynamics by analyzing both field and modeling data.

Directional reflectance distributions spanning the entire exitance hemisphere were measured in two field studies; one using a Mark III 3-band radiometer and one using the newly developed rapid scanning bidirectional field instrument called PARABOLA. Surfaces measured included corn, soybeans, bare soils, grass lawn, orchard grass, alfalfa, cotton row crops, plowed field, annual grassland, stipa grass, hard wheat, salt plain shrubland, and irrigated wheat. In addition, some structural and optical measurements were taken. Analysis of field data showed unique reflectance distributions ranging from bare soil to complete vegetation canopies. Physical mechanisms causing these trends were proposed based on scattering properties of soil and vegetation. Soil exhibited a strong backscattering peak toward the sun. Complete vegetation exhibited a "bowl" distribution with the minimum reflectance near nadir. Incomplete vegetation canopies showed shifting of the minimum reflectance off of nadir in the forward scattering direction because both the scattering properties of the vegetation and soil were being observed.

The 3-D model was developed and is unique in that it predicts (1) the directional spectral reflectance factors as a function of the sensor's azimuth and zenith angles and the sensor's position above the canopy, (2) the spectral absorption as a function of location within the scene, and (3) the directional spectral radiance as a function of the sensor's location within the scene. Initial verification of the model as applied to a soybean row crop showed that the simulated directional data corresponded relatively well in gross trends to the measured data. The model was expanded to include the anisotropic scattering properties of leaves as a function of the leaf orientation distribution in both the zenith and azimuth angle modes. The model was applied to complete vegetation canopies of various geometric structures, and it was found that the unique canopy reflectance distribution characteristics were supported by the initial field measurements. The dynamics of these distributions were physically explained by directional scattering effects of two mechanisms.

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MEASUREMENT AND MODELING OF THE OPTICAL SCATTERING PROPERTIES OF CROP CANOPIES

V. Vanderbilt and L. Grant

This research is measuring, analyzing, and mathematically modeling the specular, polarized, and diffuse light scattering properties of several plant canopies and their component parts (leaves, stems, fruit, soil) as a function of view angle and illumination angle. The potential of these bidirectional radiation properties for ground cover discrimination and condition assessment is being evaluated. To properly characterize the phenomena at various scales and to investigate the effect of the atmosphere, measurements are being made in the laboratory and in the field and will be made from a light aircraft.

During the first year, our objectives were (1) to demonstrate our new technique for determining the specular and diffuse components of the reflectance factor of plant canopies, (2) to acquire the measurements and begin assembling a data set for developing and testing canopy reflectance models, (3) to design and build a new optical instrument to measure the light scattering properties of individual leaves, and (4) to use this instrument to survey and investigate the information in the light scattering properties of individual leaves of crops, forests, weeds, and horticulture.

In achieving each of these objective, we have discovered several new results. For the wheat canopies used to demonstrate our new technique, specularly reflected light was as much as 50% of the total reflected light for some view/illumination directions. And for individual corn leaves, 85% of the light reflected at the Brewster angle was found to be specular. This means that specular light cannot be ignored for purposes of modeling the canopy reflectance.

Both the specular and diffuse portions of leaf reflectance factor vary significantly with species -- and the specular portion is possibly a major source of noise in DK-2 type reflectance measurements in chlorophyll absorption regions of individual leaves. Furthermore, our results suggest it is virtually impossible to separate for most species the specular and diffuse components of leaf reflectance using a DK-2 with integrating sphere.

Finally, our results include the discovery of two relationships potentially useful for assessing the condition of remotely sensed crops. We found a linear, inverse relationship between the relative water content (RWC) of corn leaves and their diffuse reflectance factor in the red wavelength region. The relationship appears valid even for an RWC greater than 80% where other investigators have found the middle infrared hemispherical leaf reflectance to be a poor estimator of RWC. Another result we found is a linear relationship between the severity of wheat rust on a leaf and the specular portion of its reflectance factor.



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# REFLECTANCE MODELING

A. Strahler  
Hunter College

Key to Geography

The broad objective of this research is to increase our general understanding of the bidirectional reflectance distribution function of vegetation (primarily, forest) canopies. The main thrust of the work being conducted at Hunter College is in the modeling of spectral responses of discontinuous conifer forest canopies, considered as collections of conical forms that are illuminated at an angle and cast shadows on a contracting background. This work leads from the development of an early invertible coniferous forest canopy reflectance model that allowed direct estimation of the height and spacing of conifers from the pixel-to-pixel variances of image brightness values in Landsat scenes. The three first-year objectives are now complete. These are: (1) modification of the variance-driven model to incorporate overlapping of shadows and crowns; (2) collection and analysis of photographic data to calibrate tree-spacing functions; and (3) collection of field data to determine height, spacing, and shape of conifers in open and closed stands in the Goosenest (California) test area.

Modification of the invertible model uses a linear approximation to correct for the reduction in shadow and canopy area that occurs when shadows fall on crowns or tree crowns intersect. Comparison of the results of the approximation with a series of Monte Carlo simulations shows that the mean area covered by crowns or shadows is approximated quite accurately, but the variance calculated departs significantly from simulated values. The analysis of tree spacing patterns using air photos showed that spacing tended to be somewhat regular at a scale approximately equal to the average distance between trees, but at larger distance scales counts of trees in cells could be approximated acceptably by a Poisson (random) function. Field measurements show that the short-distance regularity observed on air photos is an artifact of the inability to distinguish individual trees when their crowns overlap significantly, and that trees of the same size are often found growing in close proximity.

For the remainder of the second year, work will continue on inverting the overlapping model and on analyzing the field data to incorporate observed height, spacing, and form functions into the model. Additional efforts will be developed to assemble and register data from Thematic Mapper simulator, Landsat 4 MSS, SPOT simulator, Airborne Imaging Spectrometer, and a 30-m digital terrain model in order to help validate the model.

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A STUDY OF THE RELATION BETWEEN CROP GROWTH  
AND SPECTRA REFLECTANCE PARAMETERS

<sup>June 1977</sup>  
G. Badhwar  
NASA/JSC

The basic broader objectives of this research effort are: (1) To investigate the dynamic behavior of canopy reflectance versus time and the relationship that such trajectories bear to canopy dynamics, for example, ontogeny and morphology. (2) To understand which transformations of spectral data are "best" for observing key canopy characteristics, such as Leaf Area Index (LAI) and vegetation identification. (3) To formulate physical basis for understanding how various spectral transform trajectories depend on vegetation type and interaction of reflectance in chlorophyll and water absorption bands to monitor stress. (4) As part of the physical understanding process, evaluate and improve canopy radiative transport models.

As part of first year objectives, a differential equation describing the temporal behavior of greenness,  $G(t)$ , with time was developed. The basic equation,  $\frac{dG(t)}{dt} = k(t)(1 - \frac{G(t)}{G_m})$  where  $G_m$  is the saturation value of greenness at time,  $t_p$ .

It has been demonstrated that  $k(t)$ , has the form of a law,  $k(t) = 2[1/t + 1/t_p - t]$  and that  $k(t)$  is linearly proportional to the rate of change of leaf area index. This provides, a technique to estimate leaf area index.

It was demonstrated that  $G_m$ ,  $t_p$  and profile width, , are the key to vegetation identification and that the inflection points of the profile are related to the ontogenic state of the plant. These profile features were shown to hold not only throughout the United States corn/soybean growing area, but for the first time in Argentina.

Having demonstrated the power of these features to obtain vegetation characteristics, we wish to understand why these features provide the best separation. A number of canopy reflectance models have been implemented and are being tested on corn and soybean data sets. They will be used to gain this understanding.

A mathematical technique that maximizes the sensitivity of spectral transformation to Leaf Area Index and simultaneously minimizes the sensitivity to all other variables was formulated. Initial results on corn and wheat have been obtained.

MIT

### III.B.2. SCENE RADIATION STUDIES-MICROWAVE REGIME

- A. Fung - Scattering Models in the Microwave Regime
- J. Kong - Remote Sensing of Earth Terrain
- R. Lang - Discrete Random Media Techniques for Microwave Modeling of Vegetated Terrain
- F. Ulaby - Measuring and Modeling of the Dielectric Properties and Attenuation of Vegetation
- R. Moore - Determination of the Sources of Radar Scattering
- J. Paris - Microwave Backscattering Properties of Crops

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# SCATTERING MODELS IN THE MICROWAVE REGIME

*Center for Research*

*Assistant*  
A. Fung  
U. of Kansas

The goal of the first year effort was to calculate scattering from an inhomogeneous layer with irregular boundaries to model natural terrain such as a layer of vegetation or sea ice. The inhomogeneities were modeled by spherical or disc-shaped discrete scatterers which were small compared with the incident wavelength and were in the far field of one another. It was found that the cross-polarized scattering was dominated by multiple scattering effects and was sensitive to the orientations and distributions of the scatterers. This model has been applied to interpret measurements from vegetation, snow and sea ice.

The goal of the current year is to extend the scattering model developed in the first year to handle disc-shaped scatterers which are comparable to the incident wavelength and to use the scattering model to investigate the relative merits between active versus passive sensing of soil moisture over vegetated terrain. Results indicate that scattering measurements are more sensitive to soil moisture changes than emission measurements. This is because while both types of measurements lose sensitivity to soil moisture because of the vegetation layer, the loss is greater for passive than active measurements.

In the third year the goal is to further improve the volume scattering portion of the model to permit close spacing between scatterers and to generalize the surface scattering portion of the model to include roughness scales comparable to wavelength. This should provide a general and more realistic terrain scattering model than what is currently available.

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REMOTE SENSING OF EARTH TERRAIN

W. Hu  
J. Kong  
M.I.T.

Research Lab for  
electronics

The purpose of our investigation is to develop theoretical models that are useful and practical in relating remote sensing data to the important physical parameters characterizing earth terrain. Our work is geared toward developing models that are useful in data analysis and interpretation, scene simulation, and developing new remote sensing approaches and techniques. In the first year we have developed numerous theoretical models that are applicable to the active and passive remote sensing of plowed fields, atmospheric precipitation, vegetation, and snow fields.

The development of our theoretical models has been strongly motivated by the need to interpret the data obtained from various types of earth terrain which show distinctive characteristics. The problem of microwave scattering from sinusoidal surfaces has been studied to explain the large differences in the radar backscattering cross sections and the radiometric brightness temperatures between the cases where the incident wave vector is parallel or perpendicular to the row direction. The radiative transfer theory is used to interpret the active and passive data as a function of rain rate. Both the random medium model and the discrete scatterer model is used to study the remote sensing of vegetation fields. Due to the non-spherical geometry of the scatterers there is strong azimuthal dependence in the observed data. Thus, the anisotropic random medium model and the discrete scatterer model with nonspherical particles have been developed.

In order to relate the remote sensing data to the actual physical parameters, we have studied scattering of electromagnetic waves from randomly distributed dielectric scatterers. Both the rigorous random discrete scatterer theory and the strong fluctuation theory are used to derive the backscattering cross section in terms of the actual physical parameters and the results agree well with the data obtained from the snow fields.

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DISCRETE RANDOM MEDIA TECHNIQUES FOR MICROWAVE MODELING  
OF VEGETATED TERRAIN

*Dept of Electrical  
Engineering and  
Physics*  
R. Lang  
Geo. Wash. Univ.

Microwave remote sensing of agricultural crops and forested regions has been studied. Long term goals of my research involve modeling vegetation so that radar signatures can be used to infer the parameters which characterize the vegetation and underlying ground. Vegetation is modeled by discrete scatterers viz, leaves, stems, branches and trunks. These have been replaced by glossy dielectric discs and cylinders. Rough surfaces are represented by their mean and spectral characteristics. Average scattered power is then calculated by employing discrete random media methodology such as the distorted Born approximation or transport theory. Both coherent and incoherent multiple scattering techniques are explored. Once direct methods have been developed, inversion techniques can be investigated.

During the first year scattering amplitudes were calculated for resonant but electrically thin discs and stems. Trunks were modeled by infinitely long dielectric cylinders. A coherent distorted Born theory was developed directly from Maxwell's equations for collections of scatterers having sizes comparable to a wavelength. Backscattering cross-sections for like and cross polarized returns were calculated for a multi-component vegetation layer. Cross-sections were also calculated by employing a low albedo expansion of the vector transport equations (incoherent theory). It was shown that the two methods yielded results within 3 db of each other for like polarizations; the two theories gave substantially different results for cross polarized returns. Both methods required that the albedo of the scatterers or the optical depth of the layer be small. As a consequence, the results were restricted to frequencies below 4 GHz for agricultural crops.

The coherent distorted Born theory was used to calculate the backscatter from a mature soybean crop. Both leaves and stems were modeled as thin dielectric scatterers. Physical statistics were used to characterize the distribution of leaf and stem sizes. Results of the calculations compared favorably with University of Kansas returns which were reported in the literature. The calculations showed that leaves dominated the backscatter return for HH polarization while stems were important for VV polarized returns at large angles of incidence.

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MEASURING AND MODELING OF THE DIELECTRIC PROPERTIES AND  
ATTENUATION OF VEGETATION

F. Ulaby  
U. of Kansas

*Remote Sensing Lab.*

The objectives of this investigation were: (1) to measure the dielectric properties of vegetation material--primarily agricultural plants--as a function of moisture content and microwave frequency, (2) to develop dielectric mixing models for the vegetation-water mixture, (3) to develop a model for the loss factor of a vegetation canopy, and (4) to relate the results of (1) and (2) to (3). These objectives were successfully realized; in addition, a number of interesting new results were obtained.

During the first phase of this investigation, three waveguide transmission systems covering the 1 - 2-GHz, 3.5 - 6.5-GHz, and 7.5 - 8.5GHz bands were constructed and calibrated. By measuring the magnitude and phase of the field transmission coefficient of a given sample, it was possible to calculate the real and imaginary parts of the complex dielectric constant of the sample.

Measurements were made for numerous samples of leaves and stalks of wheat and corn, and for wheat heads. Also, dielectric measurements were made of the liquid included in the vegetation material after extraction by mechanical means. These measurements explained the heretofore unexpected frequency behavior of the dielectric constant of the vegetation-water mixture. It had always been assumed in the literature that the attenuation coefficient of vegetation increases with increasing frequency because its dielectric constant is proportional to that of the pure water. We found in this investigation that the water contained in the vegetation material has a salinity of 10 to 15 0/00, which results in a vegetation dielectric constant that is about 15 times larger than that previously expected at 1 GHz. This means that the propagation loss is more than an order of magnitude greater than had previously been assumed. We expect these results to have a significant effect on future development of models of emission and scattering from vegetation canopies.

Various types of dielectric mixing models were investigated in terms of the available data, and a propagation model was developed and evaluated against direct canopy attenuation measurements. The canopy measurements were made by transmitting a signal from a radar antenna mounted atop a truck-mounted boom, and using a small antenna mounted on a rail beneath the canopy to receive it. Additional canopy attenuation measurements are planned for the Spring and Summer of 1984.



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DETERMINATION OF THE SOURCES OF RADAR SCATTERING

K.  
R. Moore and R. Zoughi  
U. of Kansas

The field of terrain-scattering is still in its early stages of development. Several theoretical techniques are available which have established the general behavior of the backscattering coefficient ( ) for the various vegetation canopies. Most of these techniques assume the vegetation canopy to be a homogeneous medium with some statistically known parameters. To develop a better backscattering model for canopies important properties such as attenuation and major backscattering source locations should be known. Fine-resolution radar backscattering measurements were proposed to determine the backscattering sources in various vegetation canopies and surface targets. The results were then used to improve the existing theoretical models of terrain scattering, and also to enhance understanding of the radar signal observed by an imaging radar over a vegetated area.

Various experiments were performed during the first year (1983) on targets such as corn, milo, soybeans, grass, asphalt pavements, soil and concrete walkways. Due to the lack of available references on measurements of this type, the obtained results will be used primarily as a foundation for future experiments. This year was also a learning period regarding the constituent backscattering characteristics of the vegetation canopies.

The second and third years will be dedicated to performing more experiments and using the results to improve the existing models. They should be more fruitful because of a better understanding of the problems associated with these types of measurements. A new radar system will also be developed to improve the measurement accuracy.

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# EFFECTS OF VEGETATION CANOPY STRUCTURE ON MICROWAVE SCATTERING

J. Paris  
NASA/JPL

The broad goal of this study is to increase the understanding of the role of canopy structure on microwave backscattering. Structure refers to the size, orientation, and vertical placement of scatterers in the canopy. The first year objectives were (1) to develop models to predict the backscattering coefficient, SIGMA0, of vegetation with explicit biophysical and explicit polarization-dependent parameters and (2) to prepare for field measurements with radar scatterometers.

Concerning technical progress, I accomplished the following: (1) the modification of the Attema and Ulaby (1977) model and its multilayer variation by Hoekman et al. (1983) to include polarization explicitly (i.e., to allow for separate backscattering cross sections, SIGMA, and extinction cross sections, Q, for each polarization), (2) the investigation of the modified model to isolate canopy element orientation parameters by the ratioing of SIGMA0 measurements for different polarization combinations, (3) the development of expressions for bistatic scattering and canopy-substrate scattering to supplement the models, (4) the performance of sensitivity analyses on these models, (5) the modification of the Attema and Ulaby model to allow for changes, (6) the use of the modified model with a seasonal corn data set from Kansas (Eger et al., 1983), and (7) the initiation of preparations for empirical measurements with the JPL radar spectrometer and the Mobile Radar Scatterometer in irrigated cropland to test the models.

Out of these efforts, I found the following: (1) the model form for cross polarization was significantly different than that for like polarization, (2) the use of ratios of SIGMA0 for different polarization combinations can isolate canopy element orientation parameters, (3) the canopy parameters, SIGMA, Q, and NAL (the number of scattering elements per unit area), play separate roles according to the thickness or density of the canopy, (4) canopy-substrate interactions can add significant contributions to the overall SIGMA0, (5) the use of explicit leaf biophysical parameters (and the ignoring of stalk and fruit parameters) in the model led to a significant improvement in the goodness of fit of the model predictions to the observations [for example, at 17 GHz with VV polarization, the  $r^2$  increased from 0.79 (that Eger et al., 1983, obtained) to 0.931], and (6) SIGMA for an average corn leaf was found to have an excellent ( $r^2$  of 0.97) power law relation to average green leaf area. Such a dramatic increase in the fit of the model will allow scientists to extract desired canopy parameters such as leaf area index and areal leaf water content from radar backscattering measurements and will pave the way for better empirical experiments to investigate the fundamental causes of backscatter by vegetation.

OMIT

### III.B.3. ATMOSPHERIC EFFECTS STUDIES

- R. Fraser - Atmospheric Effect on Remote Sensing of the Earth's Surface
- W. Pearce - The Characterization of Surface Reflectance Variation Effects of Remote Sensing
- S. Gerstl - Multidimensional Modeling of Atmospheric Effects and Surface Heterogeneities on Remote Sensing
- D. Diner - Bidirectional Spectral Reflectance of Earth Resource: Influence of Scene Complexity and Atmospheric Effects on Remote Sensing

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ATMOSPHERIC EFFECTS ON REMOTE SENSING OF THE EARTH'S SURFACE

<sup>edit 1</sup>  
R. Fraser and Y. Kaufman  
NASA/GSFC

The objective of the investigation is to determine the main causes and magnitude of the atmospheric effects on remote sensing of the earth's surface. The investigation includes theoretical study as well as measurements. The knowledge gained from this study will be used to develop atmospheric correction algorithms and to test them with satellite data.

In a theoretical investigation of the relative effects of the aerosol optical thickness, absorption, and size distribution on remote sensing, it was found that aerosol absorption has a significant effect on satellite measurements of surface reflectivity. The absorption effect is stronger for high than for low surface reflectances. The aerosol optical thickness is dominant for small surface reflectances. The accuracy of clustering algorithms depends on both parameters. The vegetation index, however, is affected by the optical thickness but only weakly affected by the absorption (Fraser and Kaufman, 1983).

A laboratory simulation of the atmospheric effect on the radiance of sunlight scattered from the earth's surface-atmosphere system was performed. This experiment verified the existence of the adjacency effect (the effect of a bright field on the radiance detected above a dark field) and was used to test 3-D radiative transfer models (Mekler, Kaufman and Fraser, 1983).

In a theoretical study it was found that atmospheric scattering resulting from the adjacency effect reduces the separability between surface classes. This new atmospheric effect is present when the field size is of the order of the atmospheric scale height (Kaufman and Fraser, 1983).

A field experiment is being conducted to measure the path radiance simultaneously with measurements of the aerosol optical thickness scattering phase function, atmospheric scattering coefficient at the surface, and the sky polarization. The measurements (partially completed) will be used to test the correlation between the atmospheric effects and the aerosol characteristics.

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CHARACTERIZATION OF SURFACE REFLECTANCE VARIATION EFFECTS ON REMOTE SENSING

W. Pearce  
EG&G

Our overall goals include the use of our Monte Carlo radiative transfer codes to simulate the effects on remote sensing in visible and infrared wavelengths of variables which affect classification. These include detector viewing angle, atmospheric aerosol size distribution, aerosol vertical and horizontal distribution (e.g. finite clouds), the form of the bidirectional ground reflectance function, and horizontal variability of reflectance type and reflectivity (albedo). These simulations are to be used to characterize the sensitivity of observables (intensity and polarization) to variations in the underlying physical parameters both to improve algorithms for the removal of atmospheric effects and to identify techniques which can improve classification accuracy.

During the first year of this effort our first objective was to revise and validate our simulation codes (CTRANS, ARTRAN, and the Mie scattering code) to improve efficiency and accommodate a new operational environment. Next, it was necessary to build the basic software tools for acquisition and off-line manipulation of simulation results. These included micro-to-mainframe communications, graphics, fast Fourier transform, linear filtering and cubic spline differentiation, integration, and interpolation. The atmospheric spread function is of prime interest in characterizing the effects of the atmosphere. It is available in one dimensional form either through differentiation (of intensities in the vicinity of an albedo boundary) or as the Fourier transform of intensities sensed over a sinusoidally varying ground albedo pattern. Since Monte Carlo results are inherently noisy, it was necessary to implement and test techniques to damp the noise while preserving the essential accuracy of the results. Our initial investigation of the effects of vertical profile variability provided a test bed.

Our initial calculations compare cases in which increasing amounts of aerosol are shifted into the stratosphere, maintaining a constant optical depth. In the case of moderate aerosol optical depth, the effect on the spread function is to scale it linearly as would be expected from a single scattering model. Varying the viewing angle appears to provide the same qualitative effect as modifying the vertical optical depth (for Lambertian ground reflectance).



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MULTIDIMENSIONAL MODELING OF ATMOSPHERIC  
EFFECTS AND SURFACE HETEROGENEITIES ON REMOTE SENSING

*Virginia A.*  
S. Gerstl  
Los Alamos Natl. Lab.

*Montreal, Que.*

The overall goal of this project is to establish a modeling capability that allows a quantitative determination of atmospheric effects on remote sensing including the effects of surface heterogeneities. Our first year objectives include (a) the adaptation of existing radiative transfer codes to remote sensing applications, (b) the implementation of a realistic atmospheric data base, (c) the definition and verification against field measurements of a coupled atmosphere/canopy model, (d) the quantitative characterization of the effects of some biophysical canopy parameters and soil surface boundary conditions on satellite-sensed MSS data. These objectives have been achieved and are being documented in refereed journal publications. Substantial progress has also been made in quantifying the effects of varying atmospheric turbidity and different non-Lambertian and specular ground reflectances on MSS data and its transforms like Greenness and Brightness.

Our most significant scientific findings provide quantitative substantiation for the following conclusions:

- (1) Atmospheric effects are the major contributions to LANDSAT MSS bands A and B (visible) while they play only a minor role in MSS bands C and D (near IR). The Kauth-Thomas greenness parameter remains invariant to large variations of atmospheric turbidity while the MSS brightness parameter is found nearly proportional to the atmospheric optical depth over uniform vegetative surfaces.
- (2) The inclusion of anisotropic leaf scattering characteristics in our canopy model is significant to explain reflectance measurements directly above the canopy but produces only negligible effects on satellite-measured data above the atmosphere.
- (3) Non-Lambertian and specular surface reflectance characteristics (BRDF) affect satellite measurements at nadir only insignificantly but can make large differences for off-nadir observations.

These results bear significance to scene identification and atmospheric effects correction algorithms as well as to canopy reflectance modeling efforts.



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BIDIRECTIONAL SPECTRAL REFLECTANCE OF EARTH RESOURCES:  
INFLUENCE OF SCENE COMPLEXITY AND ATMOSPHERIC EFFECTS ON REMOTE SENSING

D. Diner  
NASA/JPL

The overall objective of this research program is to develop practical methods for remote sensing when scene complexity and atmospheric effects modify intrinsic reflective properties. We concentrate in particular on the radiation history from ground to space of light reflected from individual leaves; the radiation is initially multiply scattered within the crop canopy, whose geometry provides a controlling influence, then scattered and attenuated as a result of transmission through the Earth's atmosphere. We are developing the experimental and theoretical tools for studying these effects quantitatively.

We have developed a new radiative transfer code which uses Fourier transforms to solve the 3-D equation of transfer. Our initial version permits inhomogeneous non-Lambertian surfaces but assumes horizontal uniformity for the atmosphere. Our computational results are in excellent agreement with Monte Carlo calculations. We verify previous studies which indicate that the influence of atmospheric scattering extends several kilometers from each surface point. We have also found that the width of the atmospheric "point-spread" function increases with increasing aerosol scale height and viewing angle relative to the nadir. We have developed a technique based on the different spatial characters of radiation directly and diffusely transmitted to space for determining atmospheric optical depth from an orbiting spacecraft. Numerical simulations using the 3-D code and including the effects of noise are extremely encouraging.

We are using laboratory apparatus to study the variation of spectral reflectance of individual leaves as a function of illumination incidence angle and reflection angle. These data can then be used in models to determine canopy scattering effects. Our initial objective has been to develop reliable spectral and angular reflectance standards. We have found it necessary to modify the existing apparatus by strengthening the frame and replacing some optical elements. We have obtained some preliminary spectra of camellia and cucumber leaves in the 0.4 - 0.9 micron range. Greatest departures from Lambertian reflectance are seen in the 0.68 micron chlorophyll absorption feature. We have also performed stress tests by observing leaf reflectance at 0.9 microns as a function of time following clipping from the stem. A reflectance increase due to loss of water has been observed.

We are currently developing a more sophisticated 3-D radiative transfer algorithm which permits horizontal inhomogeneity in the atmosphere as well as the surface. In addition to the utility of this method to atmospheric studies, we anticipate possible application to canopy modeling, treating plant canopies as a sort of scattering "atmosphere".

OMIT

### III.C. INVESTIGATION SYNOPSES

#### Synopsis Elements:

- a. Broad Goals and Investigation Objectives
- b. First Year Objectives
- c. Technical Progress and Accomplishments
- d. Results/Scientific Findings
- e. Significance to General Research Area
- f. Relationship to Other Fundamental Research SRAEC Investigations
- g. Second Year Objectives
- h. Study Participants and Affiliations
- i. Publications (SRAEC supported research)
- j. Key Visuals/Illustrations

### III.C.1. SCENE RADIATION STUDIES--OPTICAL REGIME

- J. Smith - Reflectance Modeling [Multidimensional Radiative Transfer Model Development and Extension]
- J. Norman - Bidirectional Reflectance Modeling of Non-Homogeneous Plant Canopies
- D. Kimes - Comprehensive Understanding of Vegetated Scene Radiance Relationships
- V. Vanderbilt - Measurement and Modeling of the Optical Scattering Properties of Crop Canopies
- A. Strahler - Reflectance Model [A Geometric Model for Heterogenous Canopies of Partial Cover]
- G. Badhwar - The Relation Between Crop Growth and Spectral Reflectance Parameters
- D. Diner - (see III.C.3)

## REFLECTANCE MODELING

J. Smith, K. Cooper and M. Randolph  
Colo. St. Univ.

## INVESTIGATION SYNOPSIS

### A. BROAD GOALS AND INVESTIGATION OBJECTIVES

- GENERAL UNDERSTANDING OF BRDF (BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION)
- DEVELOP AND EXTEND BRDF MODELS FOR HETEROGENEOUS CANOPIES OF PARTIAL COVER
  - ESPECIALLY PROCESS-ORIENTED MODELS DRIVEN BY PHYSICAL PARAMETERS AND MEASUREMENTS

### B. FIRST-YEAR OBJECTIVES

- COLLECT AND IMPLEMENT VEGETATION CANOPY REFLECTANCE MODELS
- BEGIN MORE FORMAL DESCRIPTION OF RADIATIVE TRANSFER PROBLEM IN CLASSICAL ATMOSPHERIC SCIENCE CONTEXT TO AID JOINT CANOPY/ATMOSPHERE MODELING

OUT  
TO  
P.75

C. TECHNICAL PROGRESS AND ACCOMPLISHMENTS

D. RESULTS/SCIENTIFIC FINDINGS

- COMPLETE CLASSICAL RTE DESCRIPTION OF VEGETATION CANOPIES
  - CALCULATION OF PHASE FUNCTIONS UTILIZING BIOPHYSICAL DESCRIPTIONS OF CANOPY MEDIA
  - SENSITIVITY ANALYSIS
  - DISTRIBUTE TO ATMOSPHERIC WORKERS
- INITIAL DEVELOPMENT OF MONTE CARLO SOIL REFLECTANCE MODEL FOR 3D SURFACES
  - INCORPORATION INTO ADDING VEGETATION REFLECTANCE MODEL FOR INITIAL CUT AT 3D SOIL EFFECTS WITH VEGETATED SURFACES
  - POTENTIAL APPLICATIONS TO NON-RENEWABLE RESOURCES

#### E. SIGNIFICANCE TO GENERAL RESEARCH AREA

- PROVIDES DIRECT SUPPORT FOR SCENE ANALYSIS, ATMOSPHERIC STUDIES, OTHER MODELING EFFORTS AND MEASUREMENT PROGRAMS
- SUPPORTS PREDICTION OF OPTICAL-REFLECTIVE RESPONSES TO VEGETATION CANOPIES

#### F. RELATION TO OTHER FUNDAMENTAL SRAEC INVESTIGATORS

- DIRECTLY RELATED TO, AND COORDINATED WITH, STRAHLER, NORMAN
- COULD INCORPORATE/RELATE TO WORK BY TUCKER, VANDERBILT, RIMES, GERSTL

#### G. SECOND-YEAR OBJECTIVES

- EXTEND PHASE FUNCTION DESCRIPTIONS TO INCLUDE GERSTL THEORETICAL LEAF ANISOTROPY TREATMENT/INDIVIDUAL LEAF BRDF'S
- EXTEND PHASE FUNCTION DESCRIPTION TO INCLUDE KIMES LEAF AZIMUTHAL ANISOTROPY DESCRIPTION
- EXPLORE MULTIDIMENSIONAL RTE EXTENSIONS - INCORPORATION INTO KIMES APPROACH
- DEVELOP SOIL THREE DIMENSIONAL REFLECTANCE MODEL COMPATIBLE WITH VEGETATION MODELS

## H. STUDY PARTICIPANTS AND AFFILIATIONS

### ● GRADUATE STUDENTS --

-M. H. RANDOLPH (PH.D. SUMMER 1983)

-K. C. COOPER (PH.D. EXP. 1985)

### ● COLLABORATORS

-A. H. STRAHLER, HUNTER COLLEGE

-J. M. NORMAN, U. NEB.

## I. PUBLICATIONS

### THESES:

M. H. RANDOLPH. 1983. A RADIATIVE TRANSFER EQUATION/PHASE FUNCTION APPROACH TO VEGETATION CANOPY REFLECTANCE MODELING. PH.D. THESIS, COLORADO STATE UNIV., FORT COLLINS.

### MANUSCRIPTS SUBMITTED:

M. H. RANDOLPH. 1984. A RTE PHASE FUNCTION DESCRIPTION OF VEGETATION CANOPIES. SUBMITTED TO IEEE TRANS. GEOSC. & REM. SENS.

### MANUSCRIPTS IN PROGRESS:

K. D. COOPER AND J. A. SMITH. 1984. A MONTE-CARLO REFLECTANCE MODEL FOR SOIL SURFACES WITH 3D STRUCTURE.



SYMPOSIA:

P. M. TEILLET, R. BROWN, J. A. SMITH, AND G. FEDEREJEUS. 1983.  
REFLECTANCE MODEL STUDIES AT THE CCRS INTERNATIONAL COLLOQ.  
ON SPECTRAL SIGN. IN REM. SENS. BORDEAU, FRANCE.

BIDIRECTIONAL REFLECTANCE MODELING OF NON-HOMOGENEOUS PLANT CANOPIES

J. Norman  
U. of Nebr.

BROAD GOALS

DEVELOP A 3-D MODEL TO PREDICT CANOPY,  
BIDIRECTIONAL REFLECTANCE FOR  
HETEROGENEOUS PLANT STANDS USING  
INCIDENT RADIATION AND CANOPY STRUCTURE  
DESCRIPTIONS AS INPUTS

YEAR - 1 OBJECTIVE

DEVELOP UTILITY PROGRAMS TO HANDLE OUTPUT  
FROM 3-D MODEL  
DEFINE LEAF SPECTRAL PROPERTIES REQUIRED  
BEGIN CODING 3-D MODEL  
MEASURE SOME SOIL BIDIR. REFLECTANCES

### TECHNICAL PROGRESS

UTILITY PROGRAMS HAVE BEEN DEVELOPED.

(SEE EXAMPLES)

SEVERAL LEAF BIDIRECTIONAL REFL. MEASURED.

SIMPLIFIED 3-D MODEL CODED BUT UNSATISFACTORY.

8 SOIL BIDIR. REFL. MEASURED - 3 SOIL ROUGHNESSES.

### RESULTS

LEAF REFL. AND TRANS. STRONGLY DEPENDENT ON  
SUN AND VIEW ANGLES.

REFERENCE SFC. REFL. DEPENDENT ON SUN AND  
VIEW ANGLES.

LEAF HEMISPHERICAL REFL. DEPENDENT ON SUN  
INCIDENCE ANGLE.

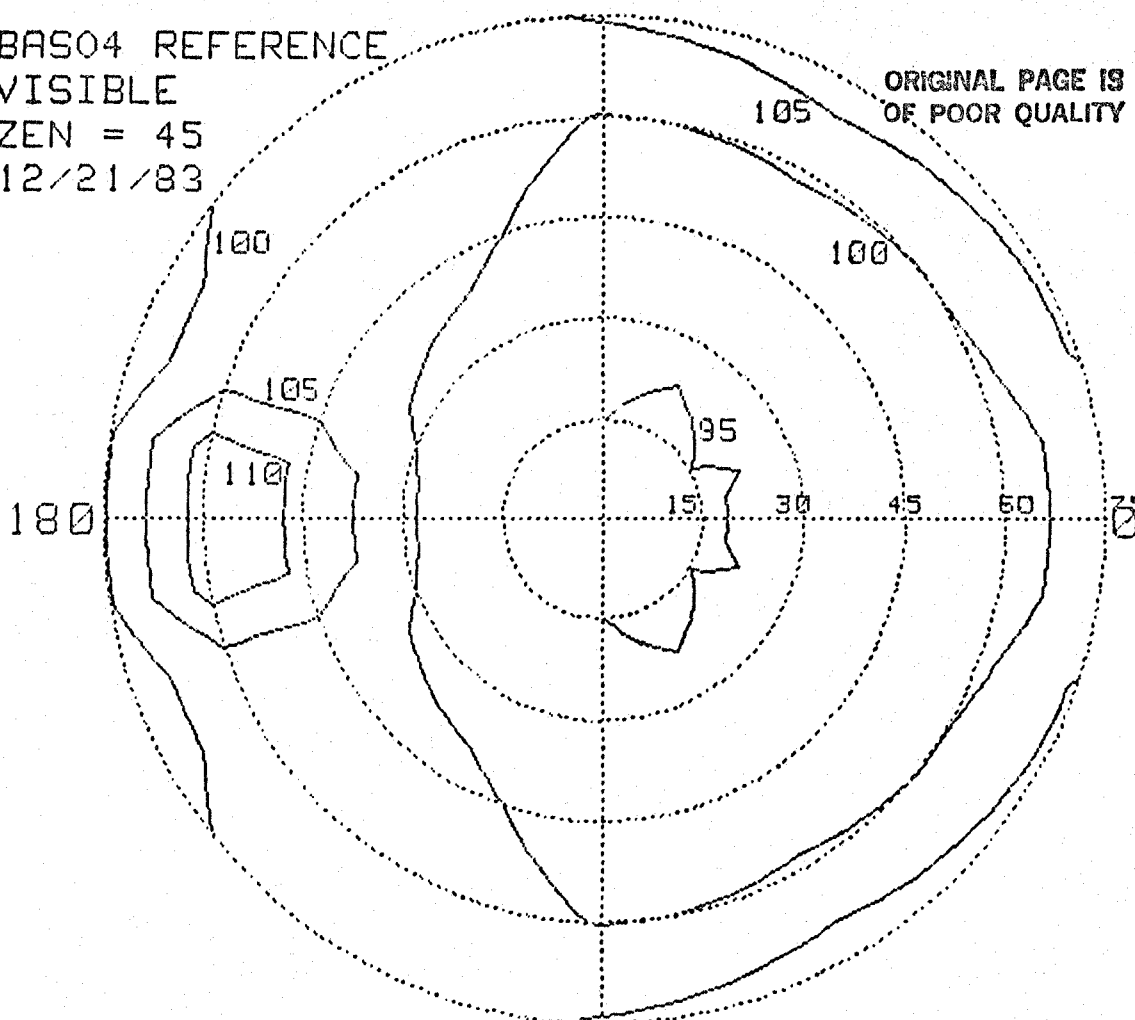
SIMPLIFIED 3-D MODEL CONTAINS MORE HORIZONTAL  
AVERAGING THAN IS DESIRABLE.

BIDIR. REFL. OF ROUGH SOIL "LOOKS" LIKE CANOPY.

BIDIR. REFL. OF SMOOTH SOIL APPROXIMATES  
LAMBERTIAN SURFACE.

BAS04 REFERENCE  
 VISIBLE  
 ZEN = 45  
 12/21/83

ORIGINAL PAGE IS  
 OF POOR QUALITY



POLAR COORDINATE CONTOURING STATUS

CONTOURING

Standard: 10  
 Interval: 5  
 Last Drawn:  
     Min: 95  
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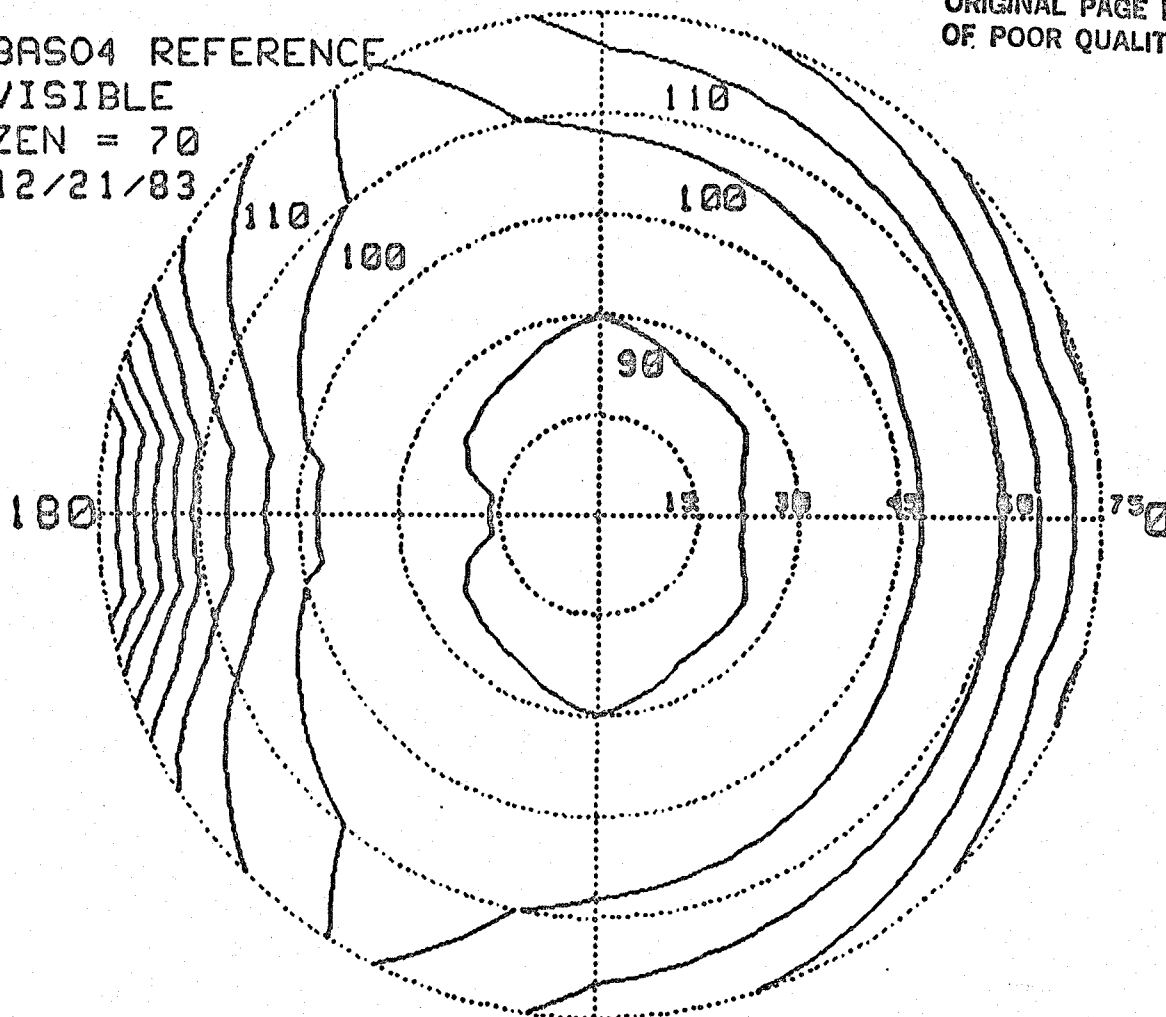
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Name: FILA1

BAS04 REFERENCE  
 VISIBLE  
 ZEN = 70  
 12/21/83

ORIGINAL PAGE 13  
 OF POOR QUALITY



POLAR COORDINATE CONTOURING STATUS

CONTOURING

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 Interval: 10  
 Last Drawn:  
 Min: 90  
 Max: 170

GRID

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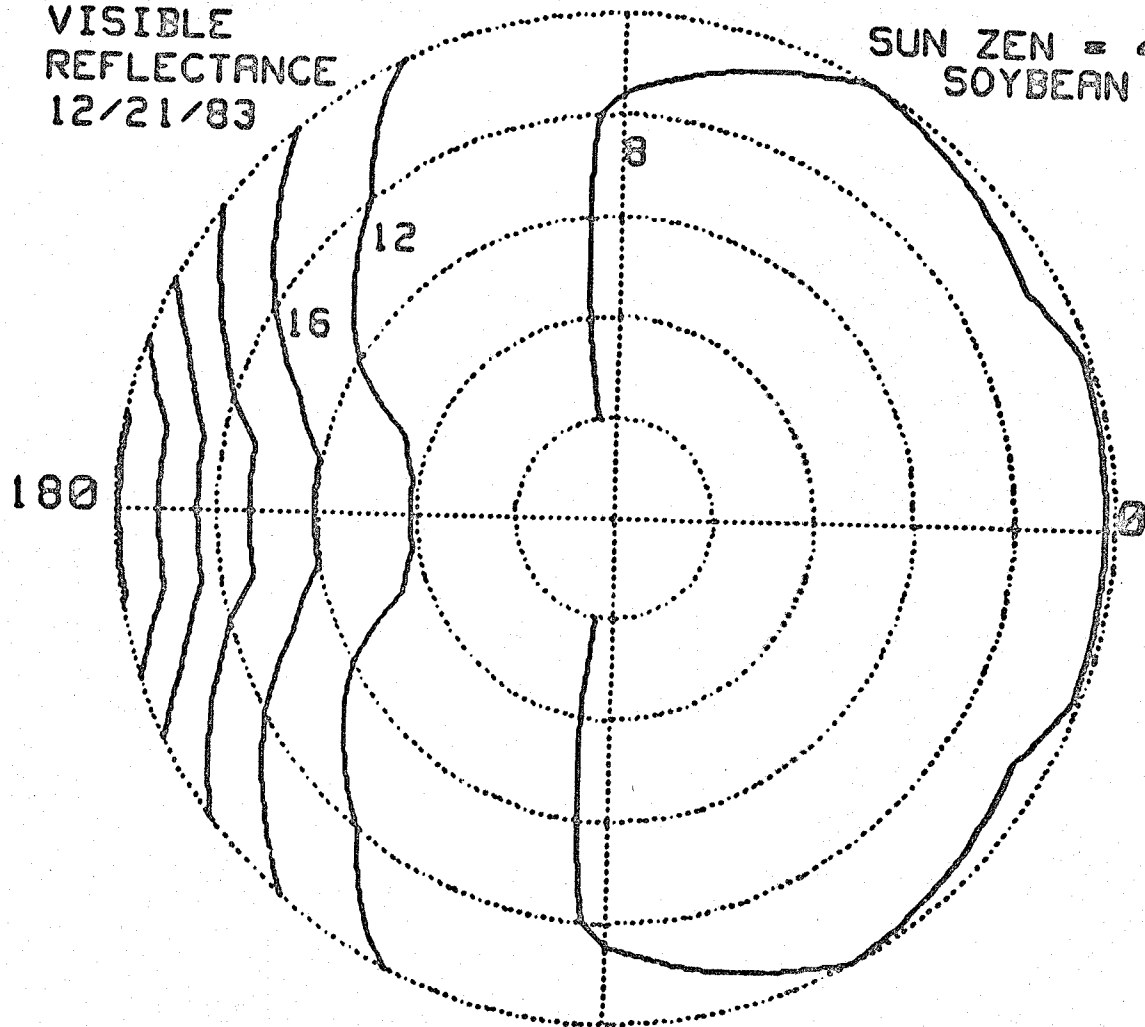
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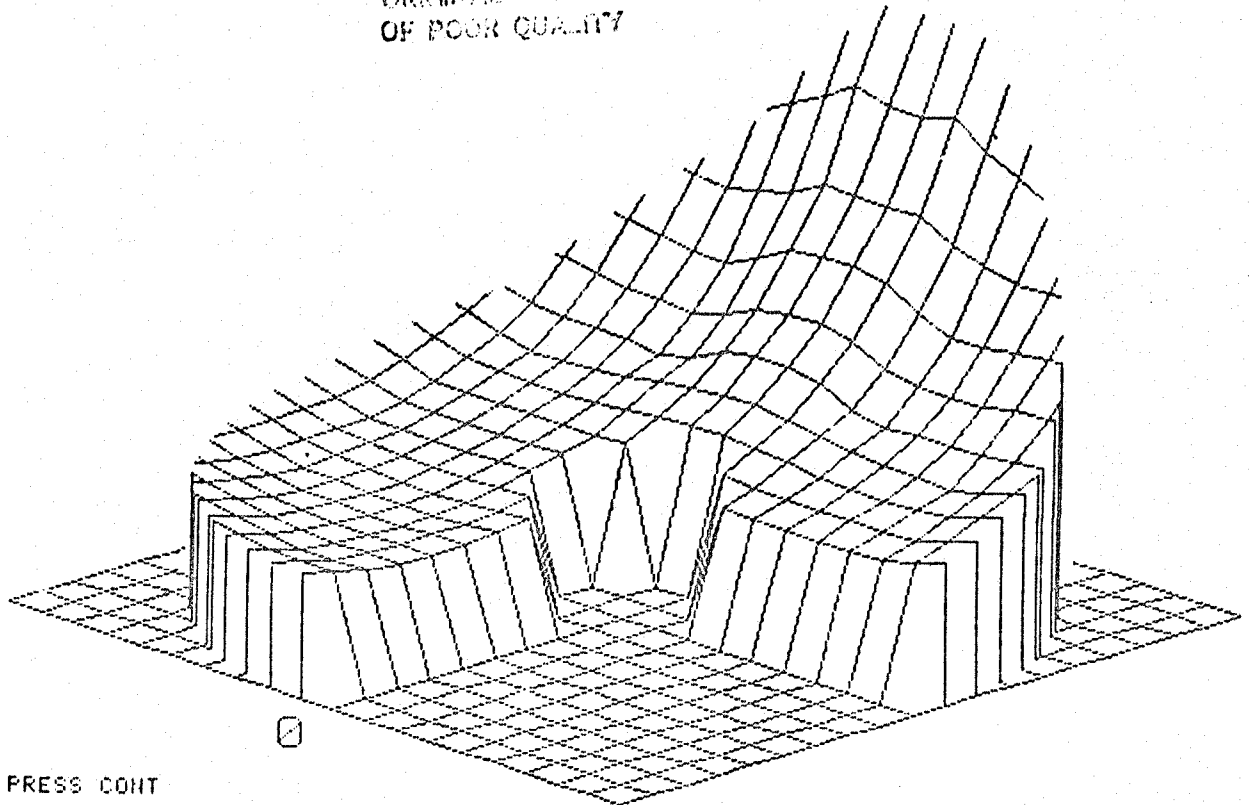
VISIBLE  
REFLECTANCE  
12/21/83

SUN ZEN = 45  
SOYBEAN



SOYBEAN VISIBLE REFLECTANCE  
SUN ZENITH = 45 deg

ORIGINAL PAGE 73  
OF POOR QUALITY

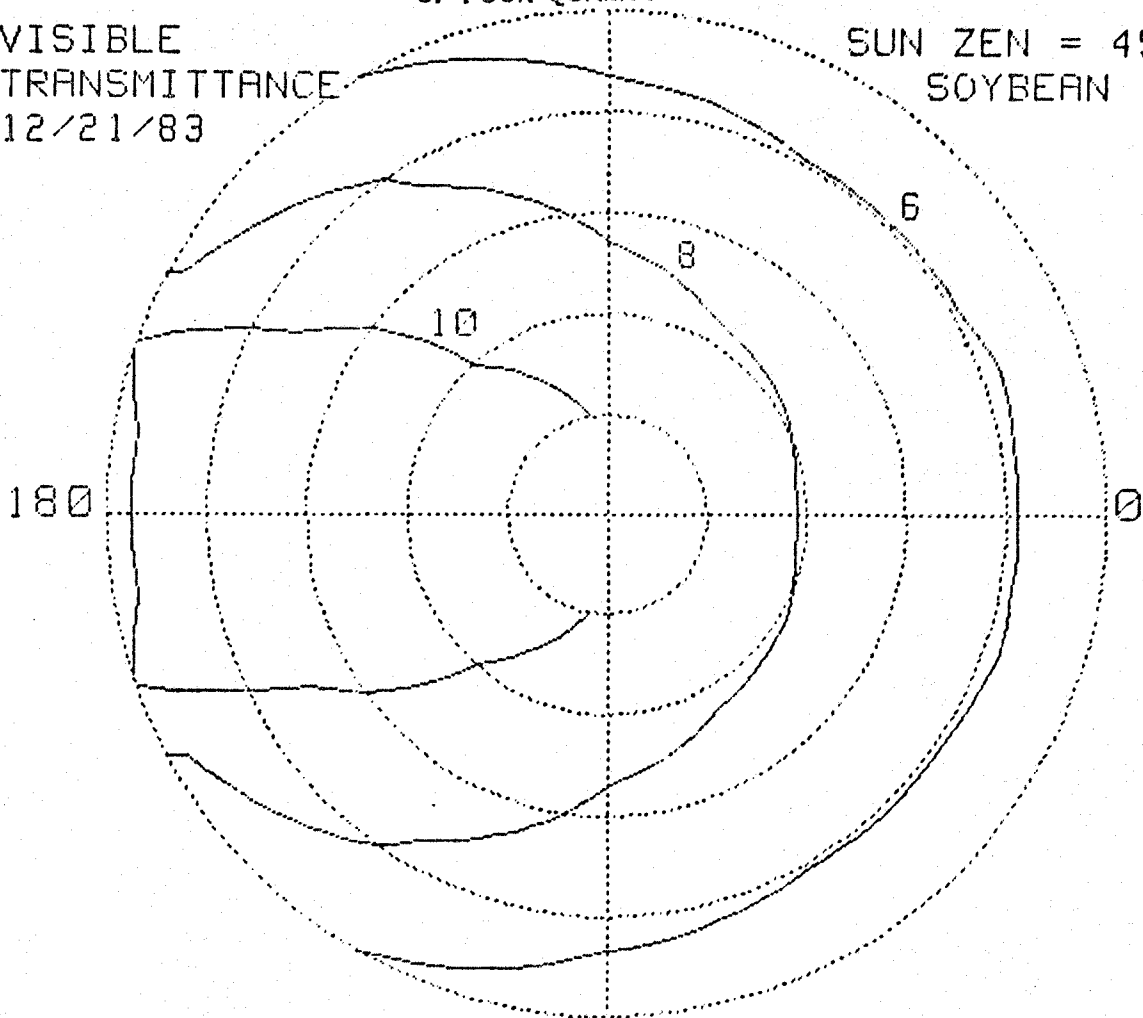


PRESS CONT

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VISIBLE  
TRANSMITTANCE  
12/21/83

SUN ZEN = 45  
SOYBEAN



POLAR COORDINATE CONTOURING STATUS

CONTOURING

Standard: 6  
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GRID

Limits: 10° to 370°  
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D(2)

MEMORY

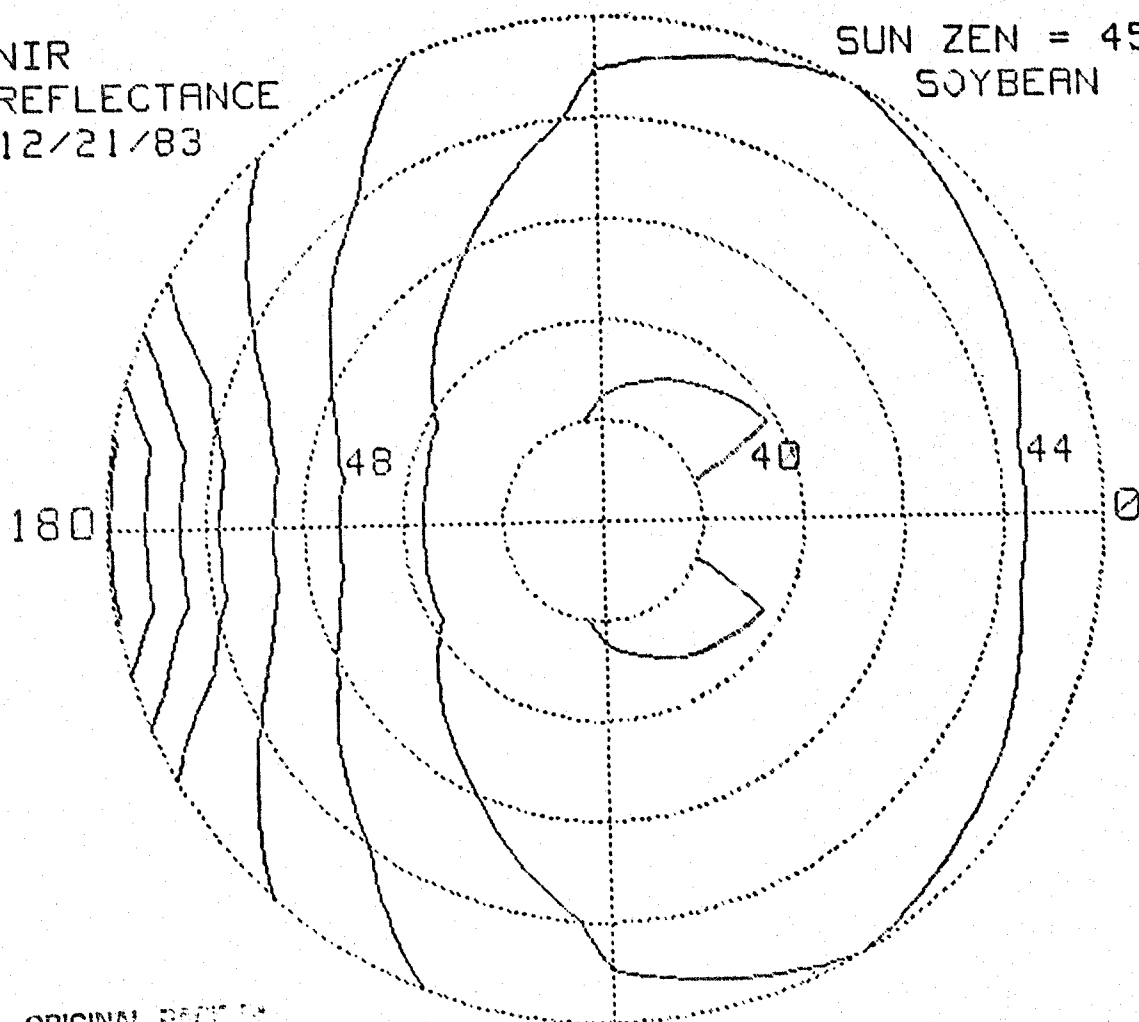
FILE

Name: FILA1



NIR  
REFLECTANCE  
12/21/83

SUN ZEN = 45  
SOYBEAN



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OF POOR QUALITY

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GRID

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D(2)

MEMORY

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COMPLETED SMOOTH

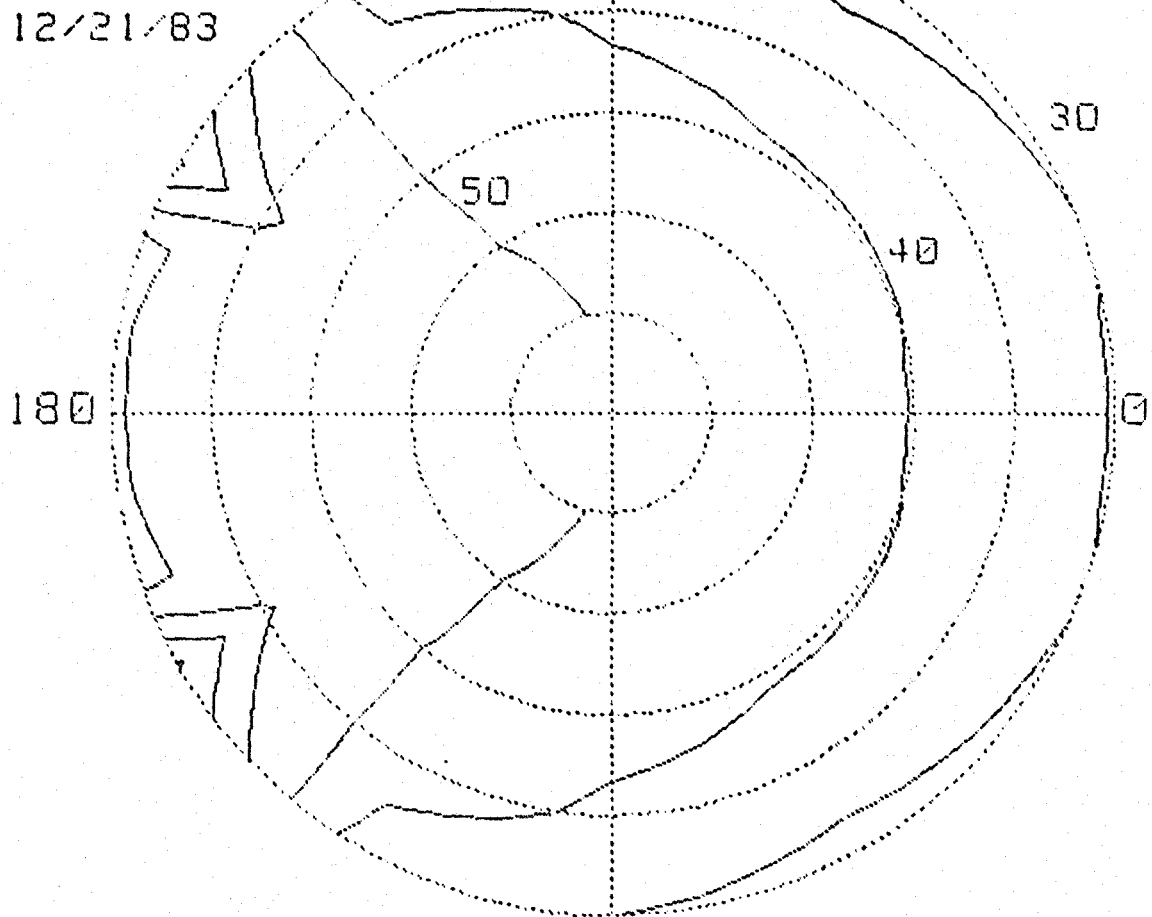
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ORIGINAL PAGE 17  
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NIR  
TRANSMITTANCE  
12/21/83

SUN ZEN = 45  
SOYBEAN



POLAR COORDINATE CONTOURING STATUS

CONTOURING

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Max: 80

GRID

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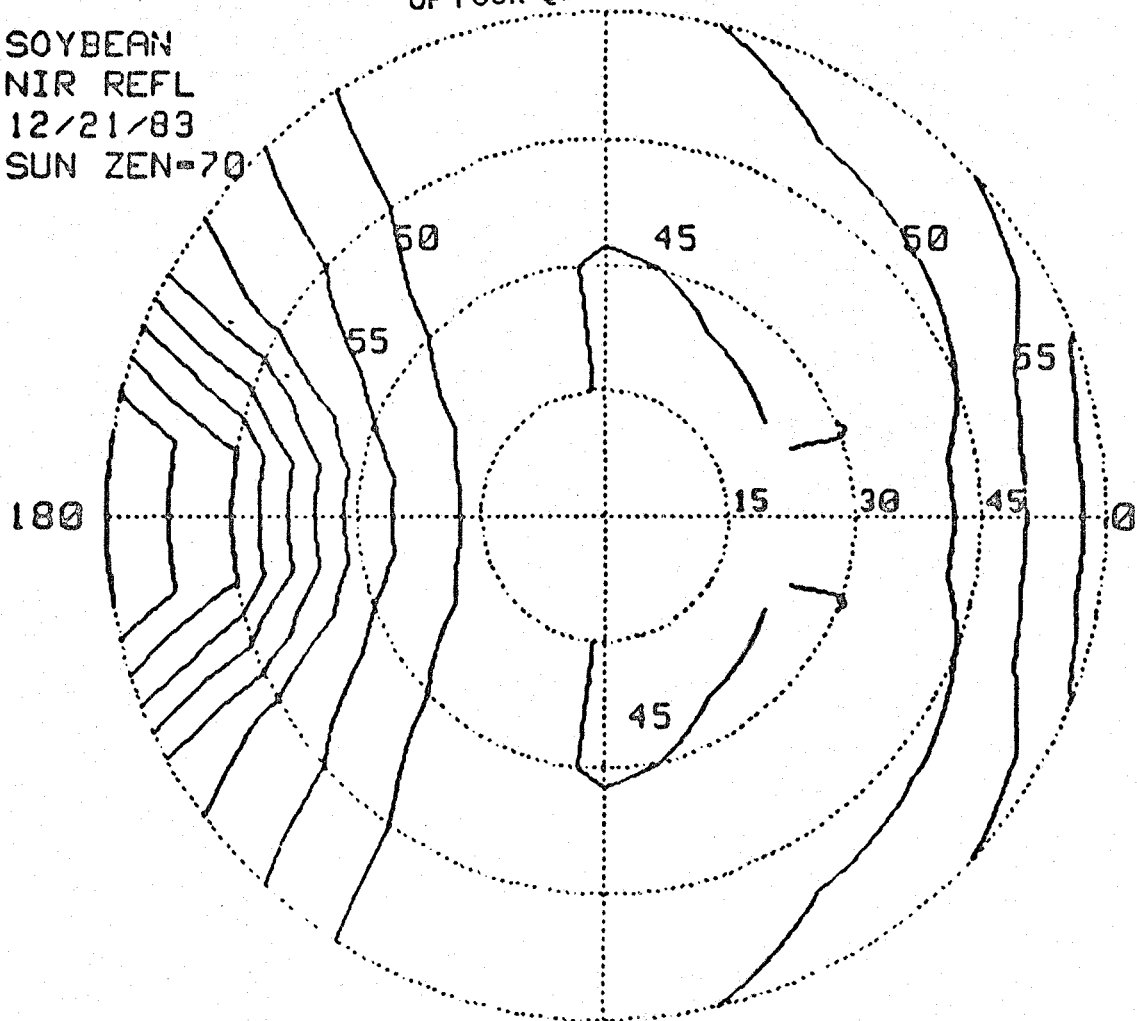
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D(2)

MEMORY

FILE  
Name: FILA1

ORIGINAL PAGE IN  
OF POOR QUALITY

SOYBEAN  
NIR REFL  
12/21/83  
SUN ZEN=70



POLAR COORDINATE CONTOURING STATUS

CONTOURING

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Last Drawn:  
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GRID

Limits: 10° to 370°  
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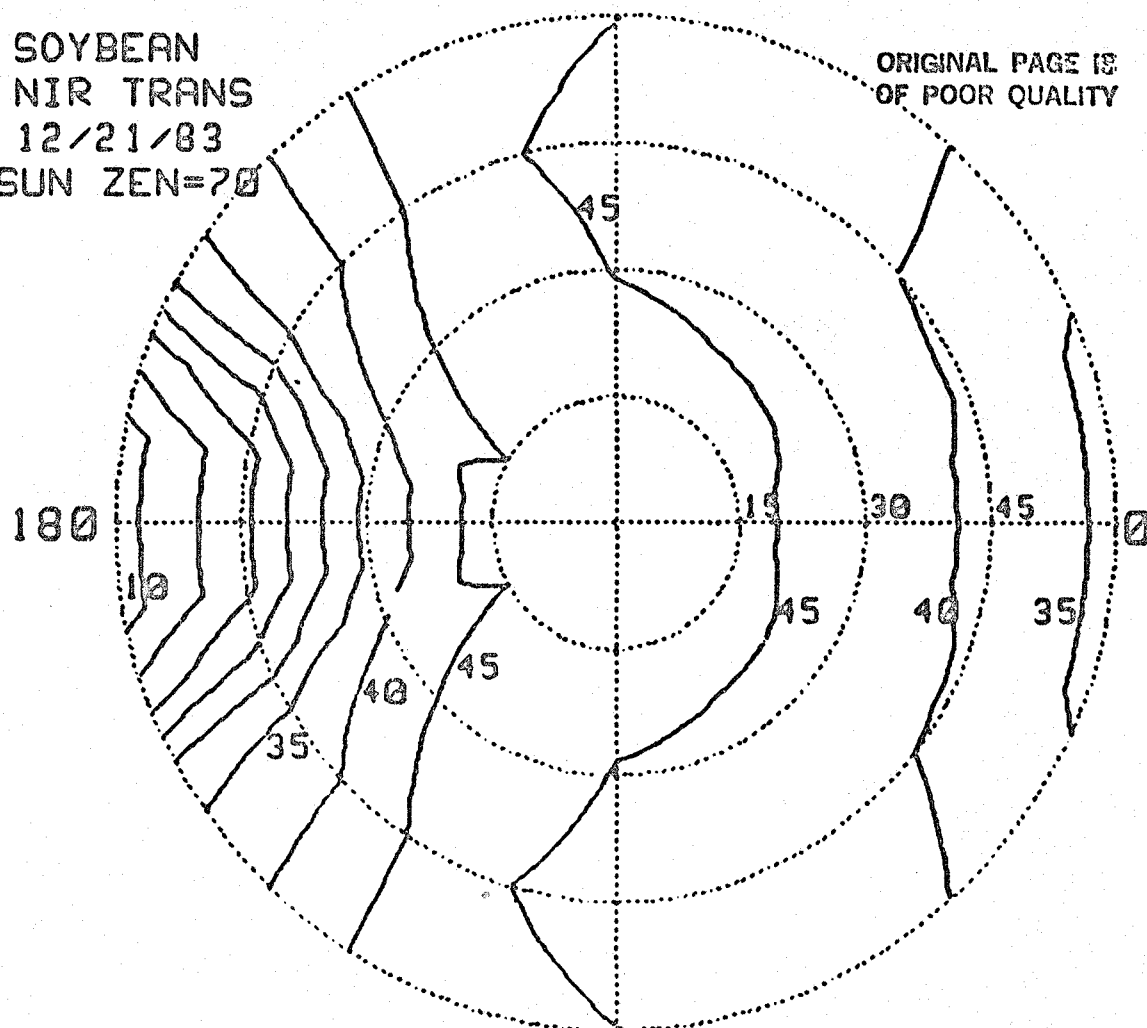
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FILE

Name:

SOYBEAN  
NIR TRANS  
12/21/83  
SUN ZEN=70

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OF POOR QUALITY



POLAR COORDINATE CONTOURING STATUS

CONTOURING

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GRID

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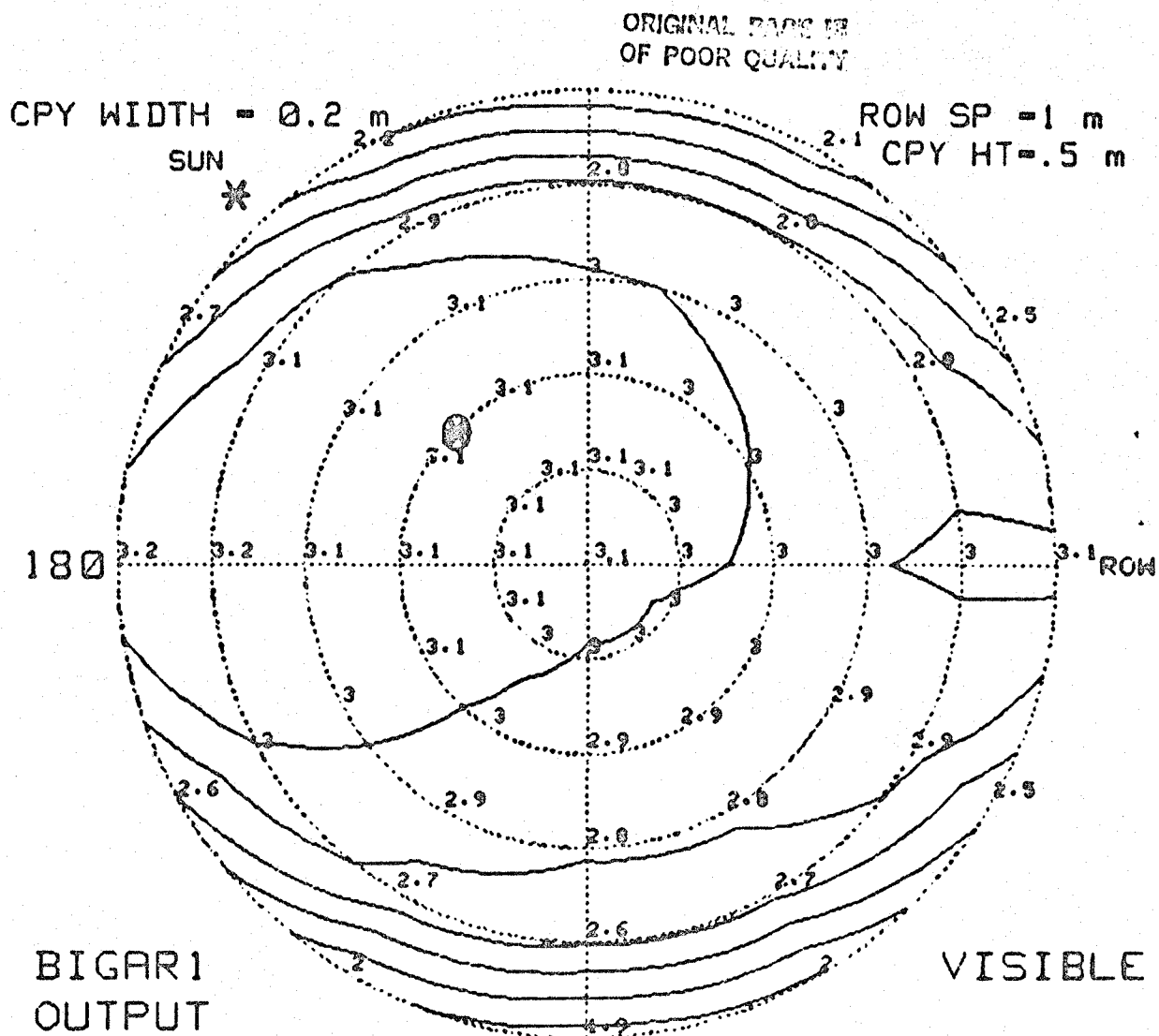
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TITLE: BIDIR LEAF TRAN COS MAT=1.544 .00 VALUES CHANGED COMPLETED SMOOTHED(1)

FILE

Name:

# Hemispherical Refl + Trans. For Soybean Leaves

	Sun zenith		
	0° (estm)	45°	70°
Visible			
Trans	7	8.2	(7.0)
Refl	8	9.6	16.1
Near-IR			
Trans	48	45.8	38.3
Refl	40	43.6	54.7



POLAR COORDINATE CONTOURING STATUS

CONTOURING

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Interval: .2  
Last Drawn:  
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Max: 3

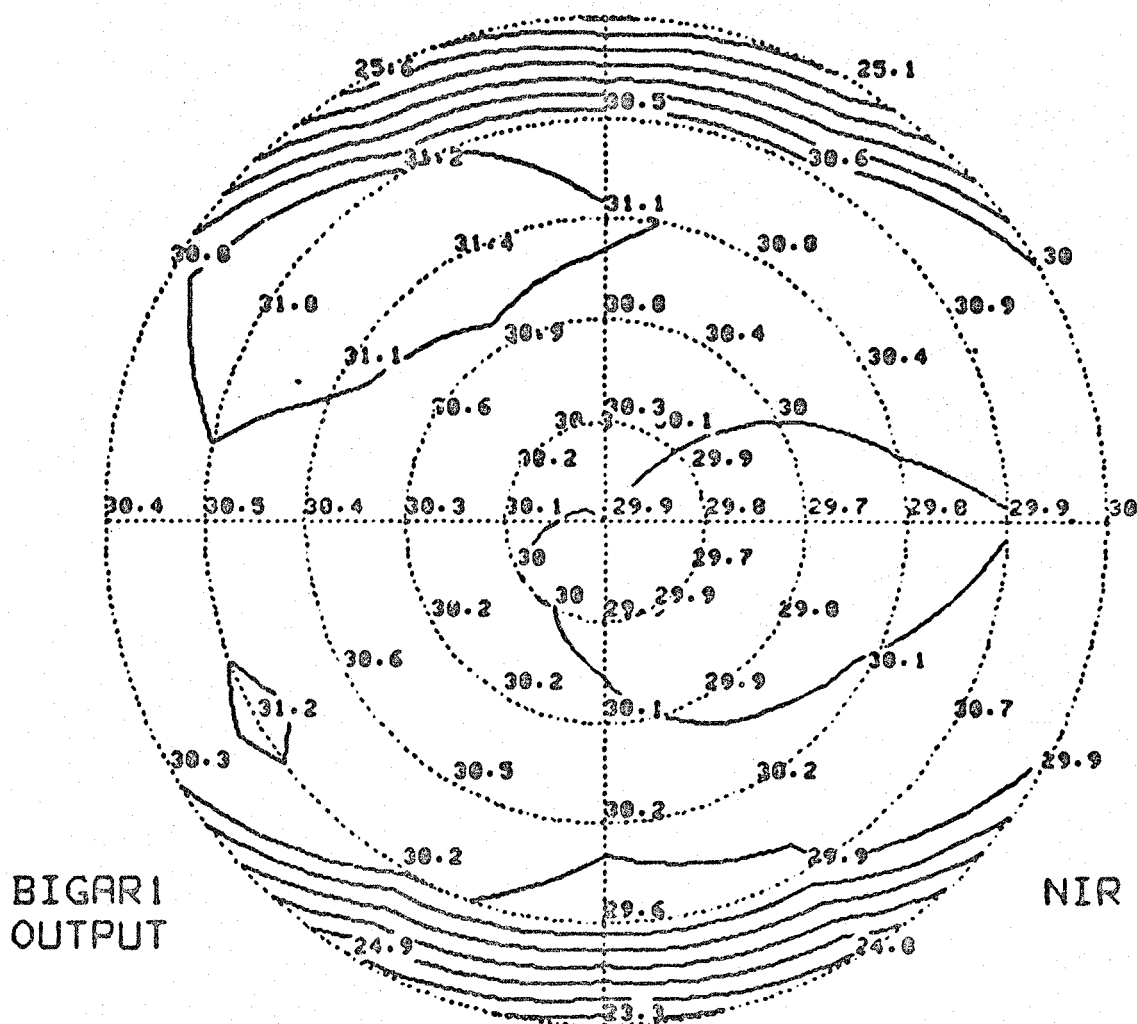
GRID

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TITLE: BIGAR1 NORMLF CASE10UT 1/6/84 10447 COMPLETED

ORIGINAL PAGE 18  
OF POOR QUALITY



POLAR COORDINATE CONTOURING STATUS

CONTOURING

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Interval: 1  
Last Drawn:  
Min: 24  
Max: 31

GRID

Limits: 0° to 360°  
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MEMORY

0 Blocks: 4

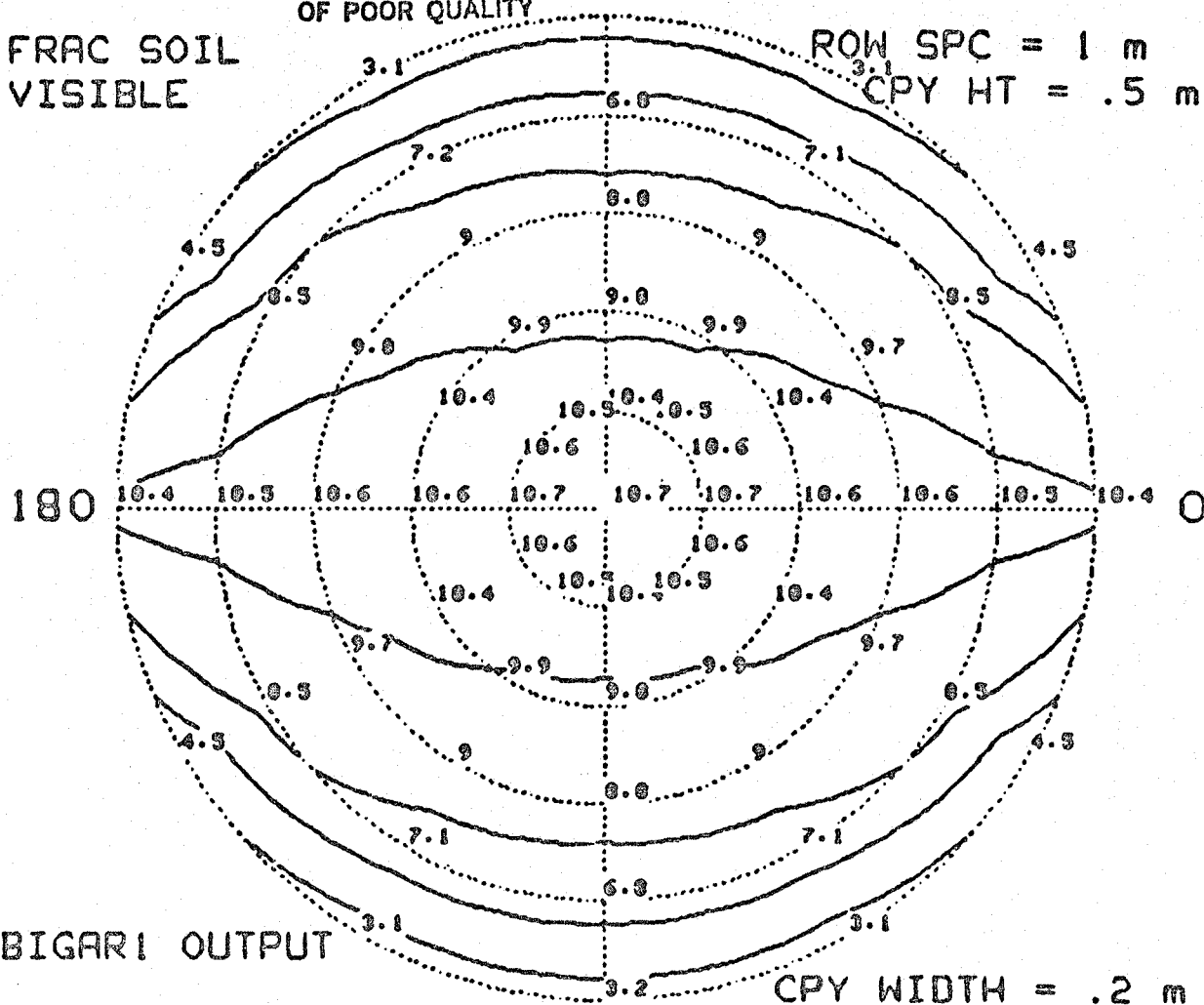
FILE

Name: FILA19

ORIGINAL PAGE 19  
OF POOR QUALITY

FRAC SOIL  
VISIBLE

ROW SPC = 1 m  
CPY HT = .5 m



POLAR COORDINATE CONTOURING STATUS

CONTOURING

Standard: 10  
Interval: 2  
Last Drawn:  
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GRID

Limits: 0° to 360°  
Theta: 1° 15° 30° 45° 60° 75°

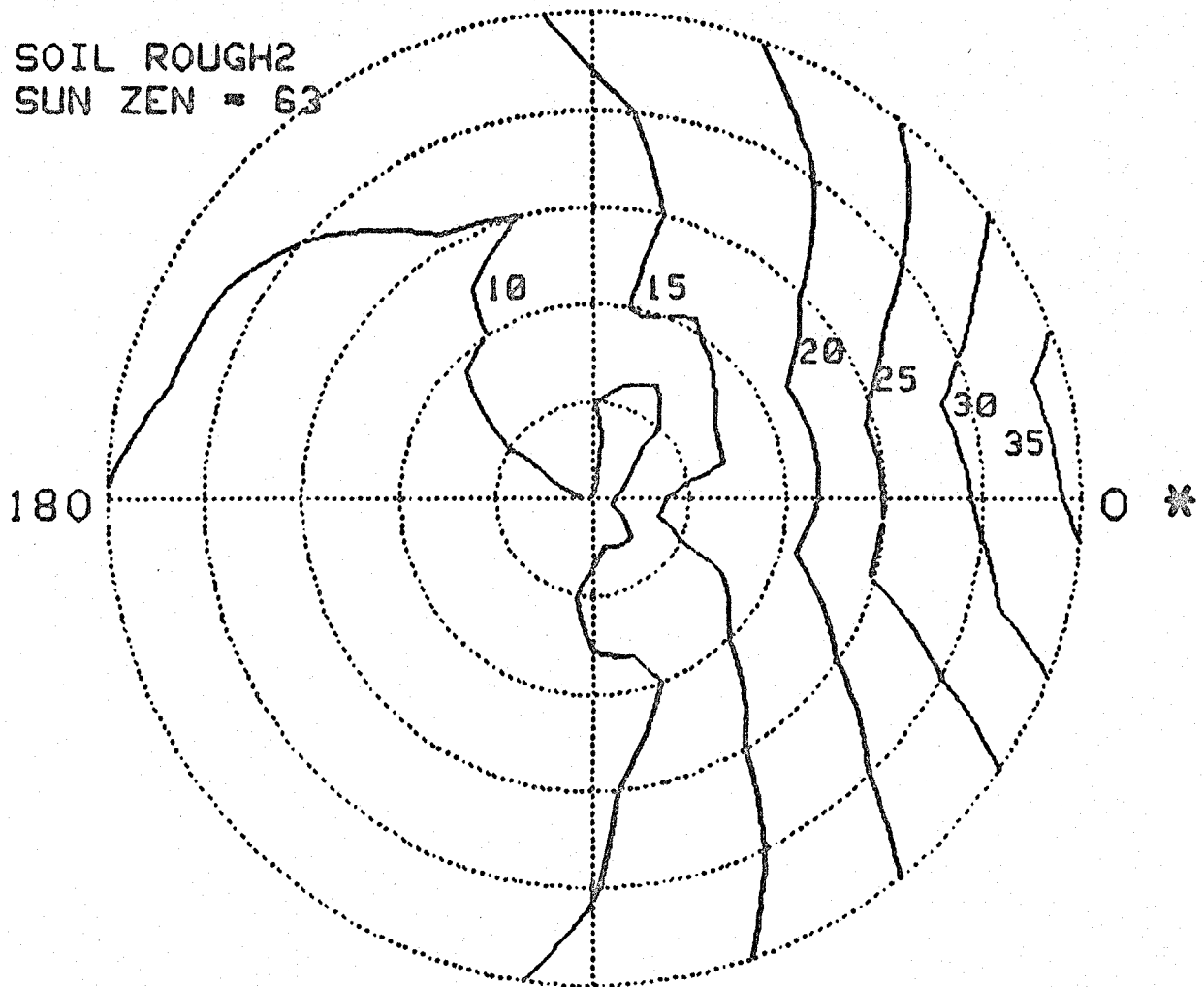
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ORIGINAL PAGE 13  
OF POOR QUALITY

SOIL ROUGH2  
SUN ZEN = 63



POLAR COORDINATE CONTOURING STATUS

CONTOURING

Standard: 10  
Interval: 5  
Last Drawn:  
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Max: 35

GRID

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Thetas: 1° 15° 30° 45° 60° 75°

DATA SET

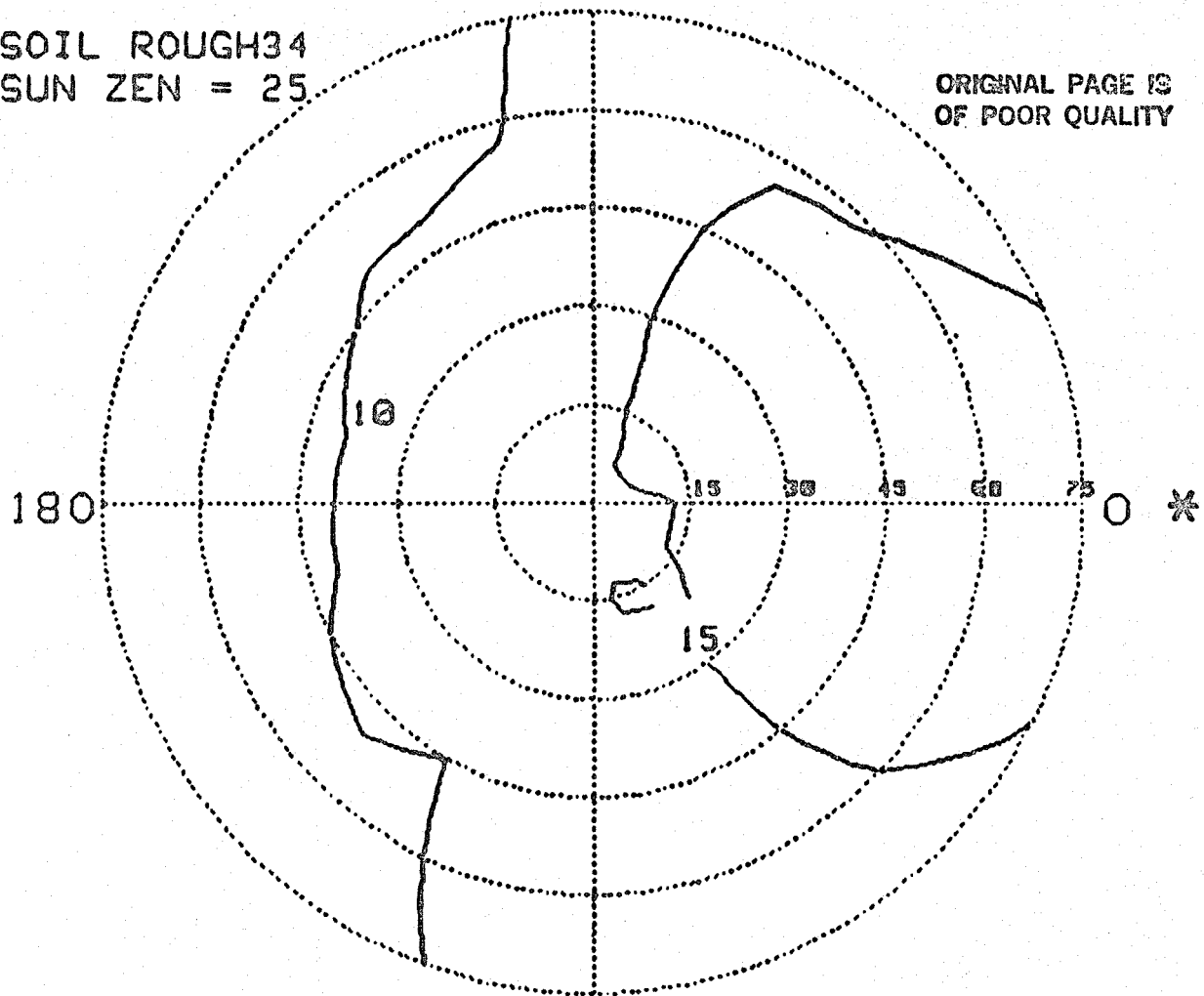
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D(1)

FILE

Name: FILD61

SOIL ROUGH34  
SUN ZEN = 25

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OF POOR QUALITY



POLAR COORDINATE CONTOURING STATUS

CONTOURING

Standard: 10  
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GRID

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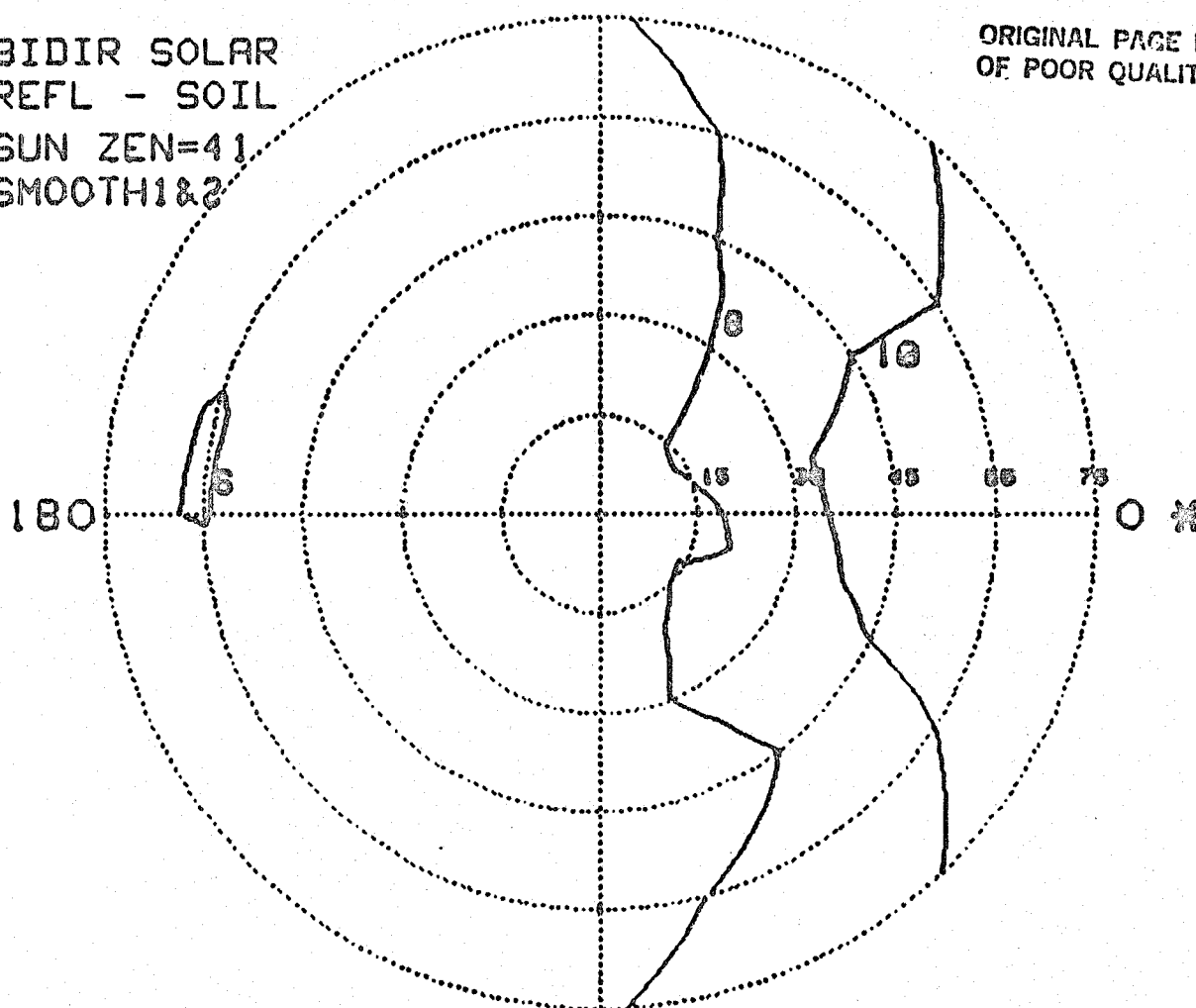
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TITLE: SOIL ROUGH4 & ROUGH4 AVERAGED SUN ZEN = 25 COMPLETED SMOOTHED(1)

MEMORY

FILE  
Name: FILE01

BIDIR SOLAR  
REFL - SOIL  
SUN ZEN=41  
SMOOTH1&2

ORIGINAL PAGE 19  
OF POOR QUALITY



POLAR COORDINATE CONTOURING STATUS

CONTOURING

Standard: 6  
Interval: 2  
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Max: 10

GRID

Limit: 0° to 360°  
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DATA SET

Block of MODIFIED (SEK 12 to store) 0 Lines: 112 / 300 0 Blocks: 4  
TITLE: SOIL SMOOTH1&2 MEAN ZEN=41 ALB=.064 SOLAR=750 REFL=49 Ha-2

MEMORY

FILE

Name: FILE62

### SIGNIFICANCE

CANOPY RADIATION MODELS HAVE BEEN USING  
NORMAL-INC LEAF REFL. SO NOT THE  
CORRECT VALUES.

REFERENCE SURFACES MAY HAVE TO BE CORRECTED  
FOR NON-LAMBERTIAN CHARACTER FOR OFF-NADIR  
REFL. MEASUREMENTS.

IT MAY BE DIFFICULT TO DISTINGUISH BETWEEN  
BETWEEN ROUGH SOILS AND SPARSE CANOPIES  
WITHOUT COMBINING WAVELENGTH AND ANGULAR  
INFORMATION TOGETHER IN A SINGLE, COMPLEX  
FORMULATION.

### RELATION TO OTHER F. R. WORK

OTHER F. R. MODELING PROJECTS (SMITH) NEED  
APPROPRIATE LEAF AND SOIL SPECTRAL AND  
ANGULAR PROPERTIES.

F. R. MEASUREMENT PROJECTS INVOLVING  
OFF-NADIR WORK SHOULD CONSIDER REFERENCE  
ANGULAR PROPERTIES.

## YEAR - 2 OBJECTIVES

COMPLETE CODING OF 3-D, BIDIR CANOPY  
REFL. MODEL.

INCORPORATE SOIL BIDIR. REFL. IN 1-D  
AND 3-D CANOPY MODELS

OBTAIN A RELATION BETWEEN HEMISPHERICAL  
LEAF REFLECTANCE AND SUN INCIDENCE ANGLE.

## STUDY PARTICIPANTS

GRAD STUDENT (FULL TIME) - BETTY WALTER

GRAD STUDENT (PART TIME) - JON WELLES

CONSULTANT - GAYLON CAMPBELL

## AFFILIATIONS

JIM SMITH

DON DEERING

## PUBLICATION (PARTIAL SUPPORT SRAEC)

NORMAN, J. M. AND J. M. WELLES, 1983. RADIATIVE  
TRANSFER IN AN ARRAY OF CANOPIES. AGRON. J.  
75:481-488.

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## COMPREHENSIVE UNDERSTANDING FOR VEGETATED SCENE RADIANCE RELATIONSHIPS

D. Kimes and D. Deering  
NASA/GSFC

### Broad Goals and Investigation Objectives

- Improve our fundamental understanding of the dynamics of directional scattering properties of vegetation canopies through analysis of field data and model simulation data.

#### First year objectives:

- Collect directional reflectance data covering the entire exitance hemisphere for several common vegetation canopies (both homogeneous and row crop structure).
- Develop a scene radiation model with a general mathematical framework which will treat 3-D variability in heterogeneous scenes and account for 3-D radiant interactions within the scene.
- Conduct initial validation of model on row crop data sets.

#### Second year objectives:

- Continue to collect reflectance distributions of vegetation canopies with various geometric structure
- Expand 3-D model to include anisotropic scattering algorithms at "cell" level.
- Continue to test and expand proposed physical scattering mechanism involved in reflectance distribution dynamics by analyzing both field and modeling data.

#### Results/Scientific Findings

- Directional reflectance distributions spanning the entire exitance hemisphere were measured in two field studies; one using a Mark III 3-band radiometer and one using the newly developed rapid scanning bidirectional field instrument called PARABOLA. Surfaces measured included corn, soybeans, bare soils, grass lawn, orchard grass, alfalfa, cotton row crops, plowed field, annual grassland, stipa grass, hard wheat, salt plain shrubland, and irrigated wheat. In addition, some structural and optical measurements were taken.
- Analysis of field data showed unique reflectance distributions ranging from bare soil to complete vegetation canopies. Physical mechanisms causing these trends were proposed based on scattering properties of soil and vegetation. Soil exhibited a strong backscattering peak toward the sun. Complete vegetation exhibited a "bowl" distribution with the minimum reflectance near nadir. Incomplete vegetation canopies showed shifting of the minimum reflectance off of nadir in the forward scattering direction because both the scattering properties of the vegetation and soil were being observed.

- The 3-D model was developed and is unique in that it predicts (1) the directional spectral reflectance factors as a function of the sensor's azimuth and zenith angles and the sensor's position above the canopy, (2) the spectral absorption as a function of location within the scene, and (3) the directional spectral radiance as a function of the sensor's location within the scene.

Initial verification of the model as applied to a soybean row crop showed that the simulated directional data corresponded relatively well in gross trends to the measured data. However, the model can be greatly improved by incorporating more realistic anisotropic scattering properties. The model was shown to follow known physical principles or radiative transfer. The model explained in physical terms the "bowl" shape distribution of complete vegetation canopies.

- The 3-D model was expanded to include the anisotropic scattering properties of leaves as a function of the leaf orientation distribution in both the zenith and azimuth angle modes.
- The model was applied to complete vegetation canopies of various geometric structures--erectophile, planophile, spherical, and heliotropic. It was found that each canopy had unique reflectance distribution characteristics which were supported by the initial field measurements. The dynamics of these distributions were physically explained by directional scattering effects of two mechanisms. The first mechanism causes the characteristic "bowl" shape or complete canopies. It is caused by shadowing gradients and view projection gradients within the canopy. The second mechanism is the primary directional scattering of the leaves due to leaf orientation, source directions, and leaf transmittance and reflectance values. The combination of these two mechanisms in the various canopies are responsible for the dynamics of the shifting reflectance minimum and the overall shape of the distributions.

#### Significance to General Research Area

- Provides hypotheses of the physical mechanisms involved in the dynamics of directional scattering of vegetation canopies.
- This body of information will aid in intelligent exploitation of remote sensing activities that deal with directional reflectance of surfaces

#### Relationship to other Fundamental Research SRAEC Investigations

- Fundamental understanding of the directional scattering properties of surfaces is essential for a full scientific understanding of the earth-atmosphere scene radiation complex.



## Study Participants and Affiliations

Julie Kirchner  
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GSFC

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G. F. Epema  
J. de Leeun

International Institute for Aerial  
Survey and Earth Sciences (ITC)  
The Netherlands

Numerous Gov't Officials

Kasserine, Tunisia, Africa

# Publications (SRAEC Supported Research)

- 1982 "Irradiance Measurement Errors Due to the Assumption of a Lambertian Reference Panel", D.S. Kimes, J.A. Kirchner, Remote Sensing of Environment, 12:141-149.
- 1982 "Radiative Transfer Model for Heterogeneous 3-D Scenes," D.S. Kimes and J.A. Kirchner, Applied Optics, 21(22):4119-4129.
- 1982 "Variation of Directional Reflectance Factors with Structural Changes of a Developing Alfalfa Canopy," J.A. Kirchner, D.S. Kimes, and J. E. McMurtrey III, Applied Optics, 22:3766-3774.
- 1983 "Directional Radiometric Measurements of Row-Crop Temperatures," D.S. Kimes and J.A. Kirchner, Int. J. Remote Sensing, 4(2):299-311.
- 1983 "Remote Sensing of Row Crop Structure and Component Temperatures Using Directional Radiometric Temperatures and Inversion Techniques," D.S. Kimes, Remote Sensing of Environment, 13:33-55.
- 1983 "Diurnal Variations of Vegetation Canopy Structure," D.S. Kimes and J.A. Kirchner, Int. J. Remote Sensing, 4(2):257-271.
- 1983 "Dynamics of Directional Reflectance Factor Distributions for Vegetation Canopies," D.S. Kimes, Applied Optics, 22:1364-1372.
- 1983 "Spectral Radiance Errors in Remote Sensing Ground Studies Due to Near By Objects," D.S. Kimes, J.A. Kirchner, and W.W. Newcomb, Applied Optics, 22:8-10.
- 1984 "Optimal Directional View Angles for Remote Sensing Missions," D.S. Kimes, B.N. Holben, C.J. Tucker, and W.W. Newcomb, Int. J. Remote Sensing, in press.
- 1984 "Modeling the Directional Reflectance from Complete Homogeneous Vegetation Canopies with Various Leaf Orientation Distribution," D.S. Kimes, Journal of the Optical Society of America, in review.
- 1984 "Directional Reflectance Factor Distributions for Cover Types of Northern Africa in NOAA 7/8 AVHRR Bands 1 and 2," D.S. Kimes, W.W. Newcomb, C.J. Tucker, I.S. Zonneveld, W. Van Wijngaarden, G.F. Epema, and J. deLeeun, Remote Sensing of Environment, in review.
- 1984 "Directional Reflectance Factor Distributions of a Cotton Row Crop," D.S. Kimes, W.W. Newcomb, J.B. Schutt, P.J. Pinter, Jr., and R.D. Jackson, Int. J. Remote Sensing, in press.

\*Note: Some of these studies were initiated before SRAEC support but were concluded with SRAEC money.

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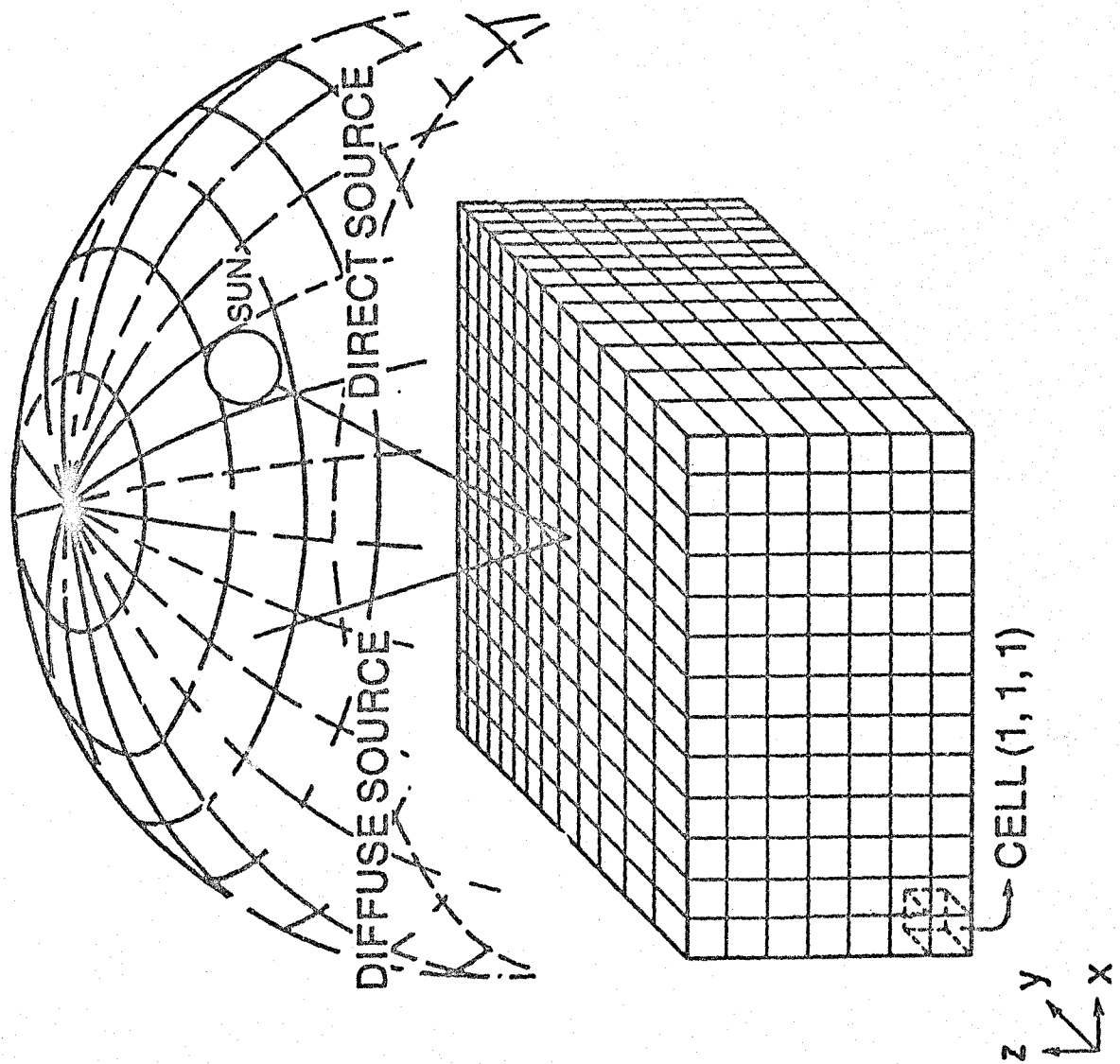


Fig. 1

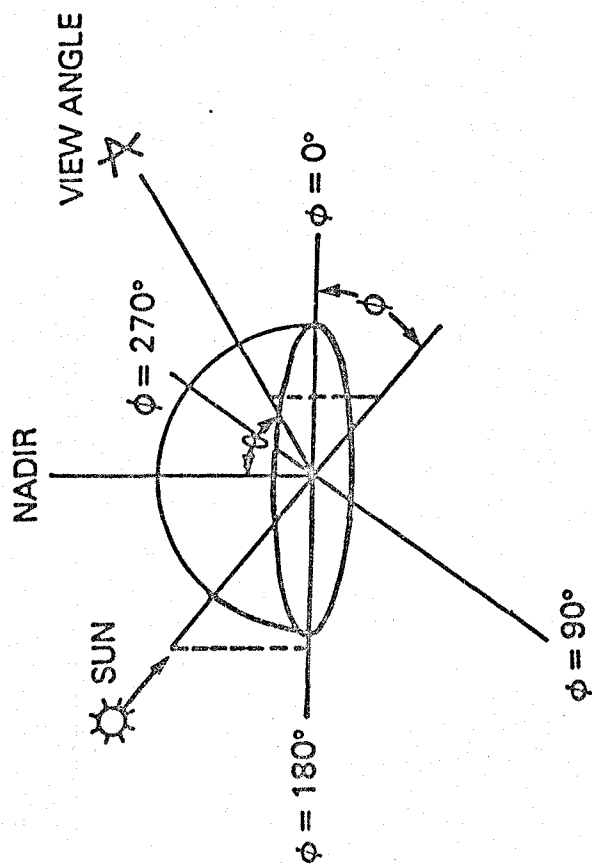
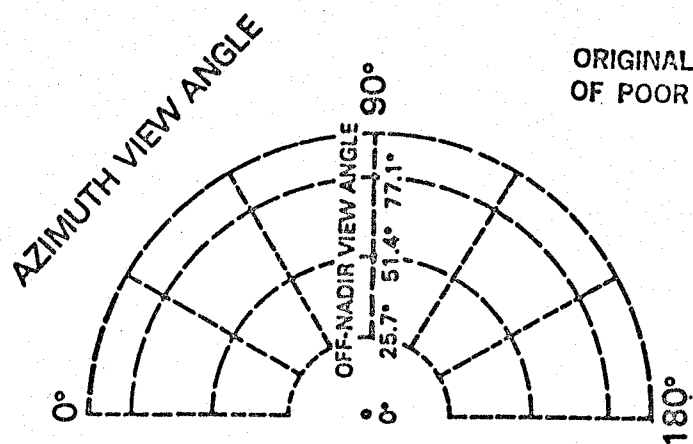


Fig. 4

# A. ERECTOPHILIE CANOPY - RED BAND

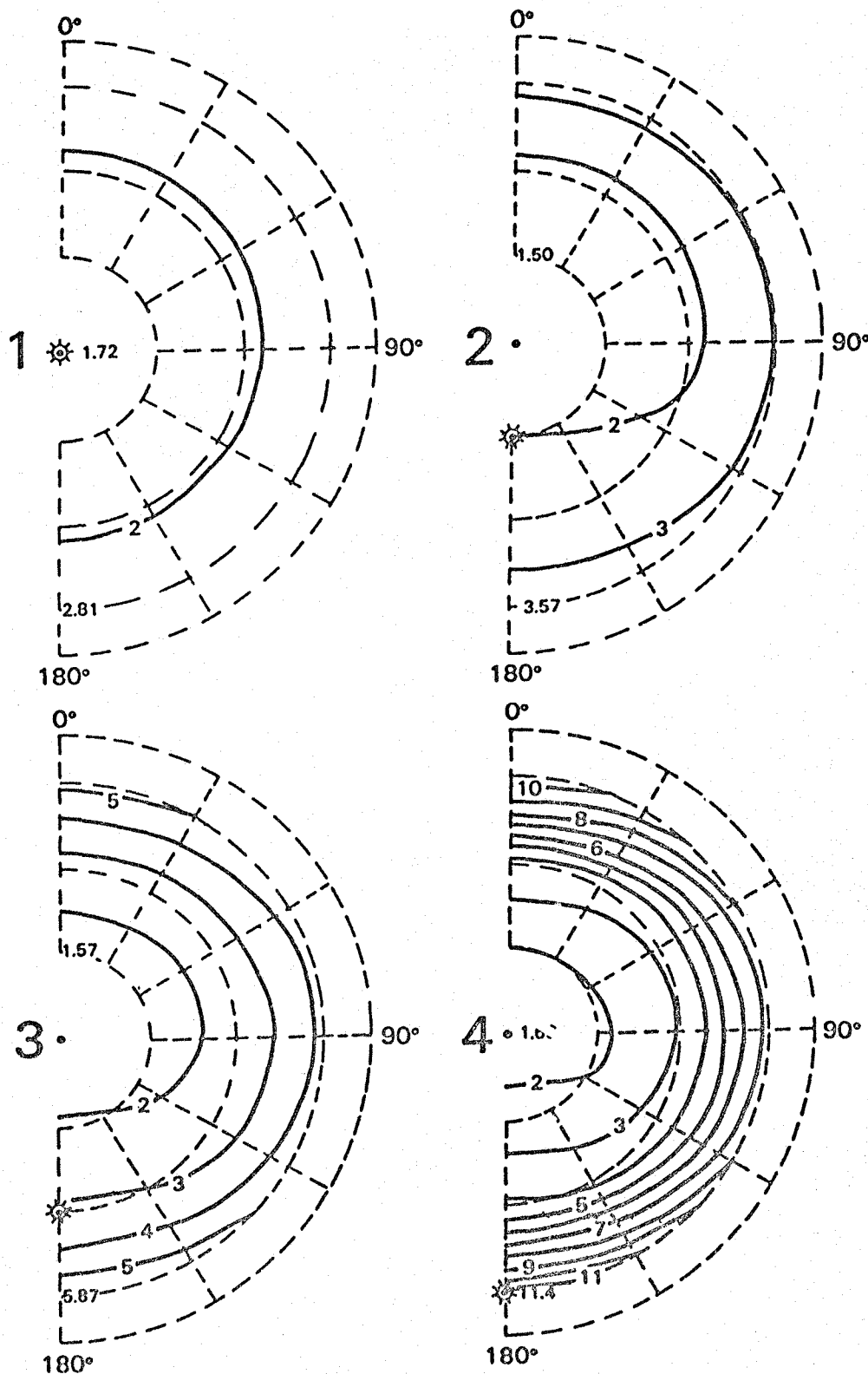


Fig. 5-A

# PLANOPHILE CANOPY - RED BAND

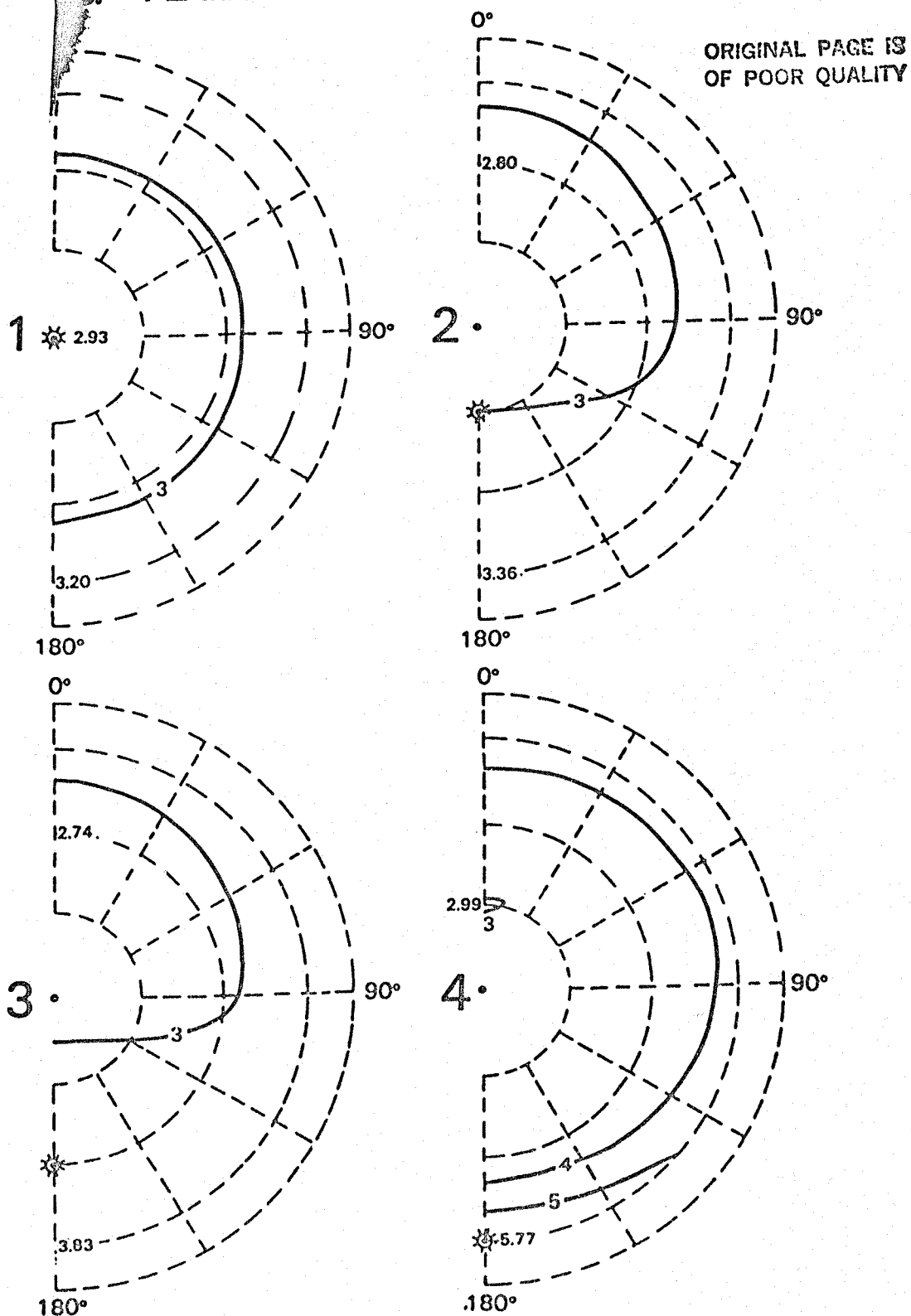


Fig. 5-C

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# D. HELIOTROPIC CANOPY - RED BAND

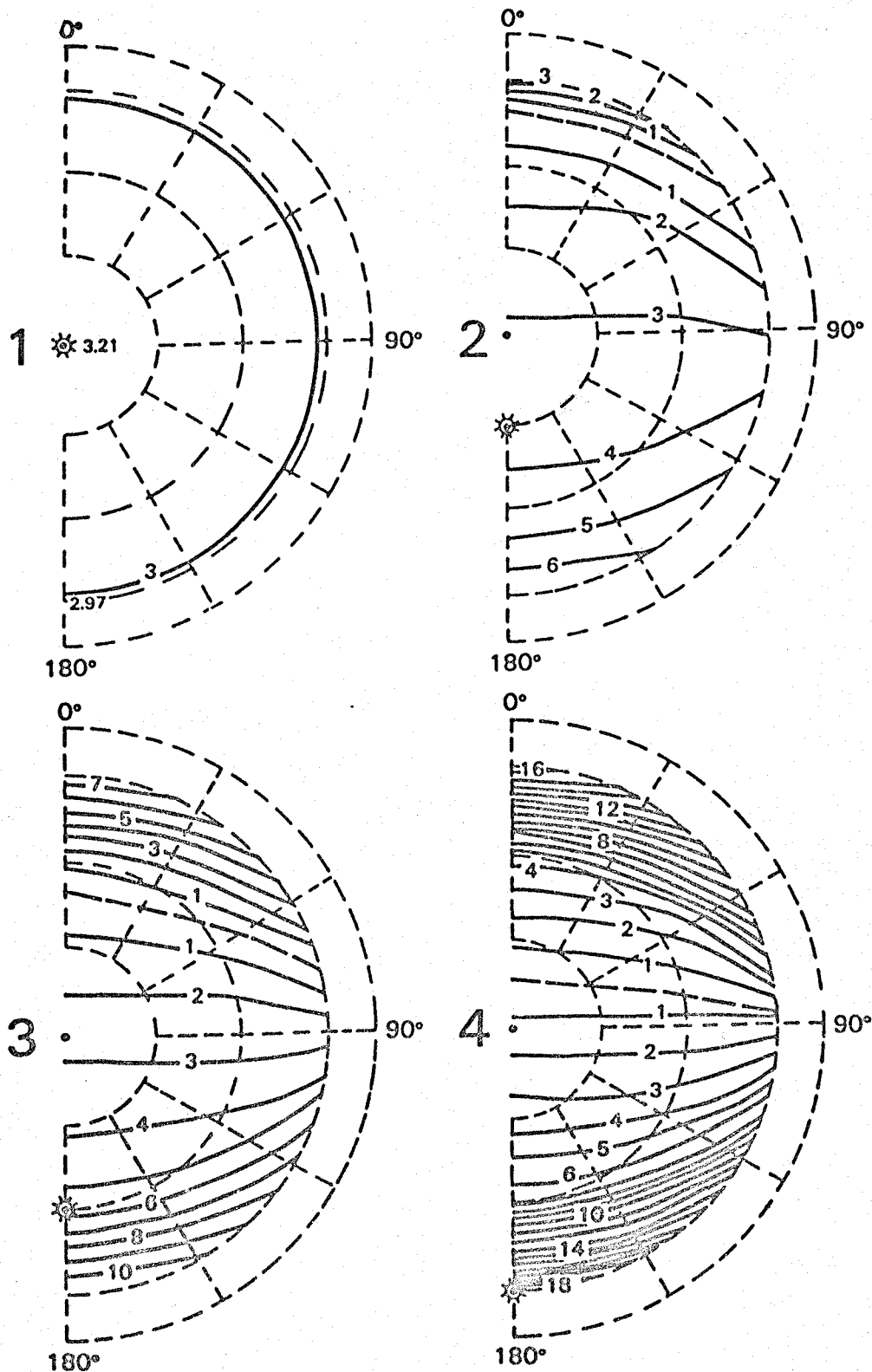


Fig. 5-D

# REFLECTANCE/TRANSMITTANCE SENSITIVITY SPHERICAL CANOPY - RED BAND

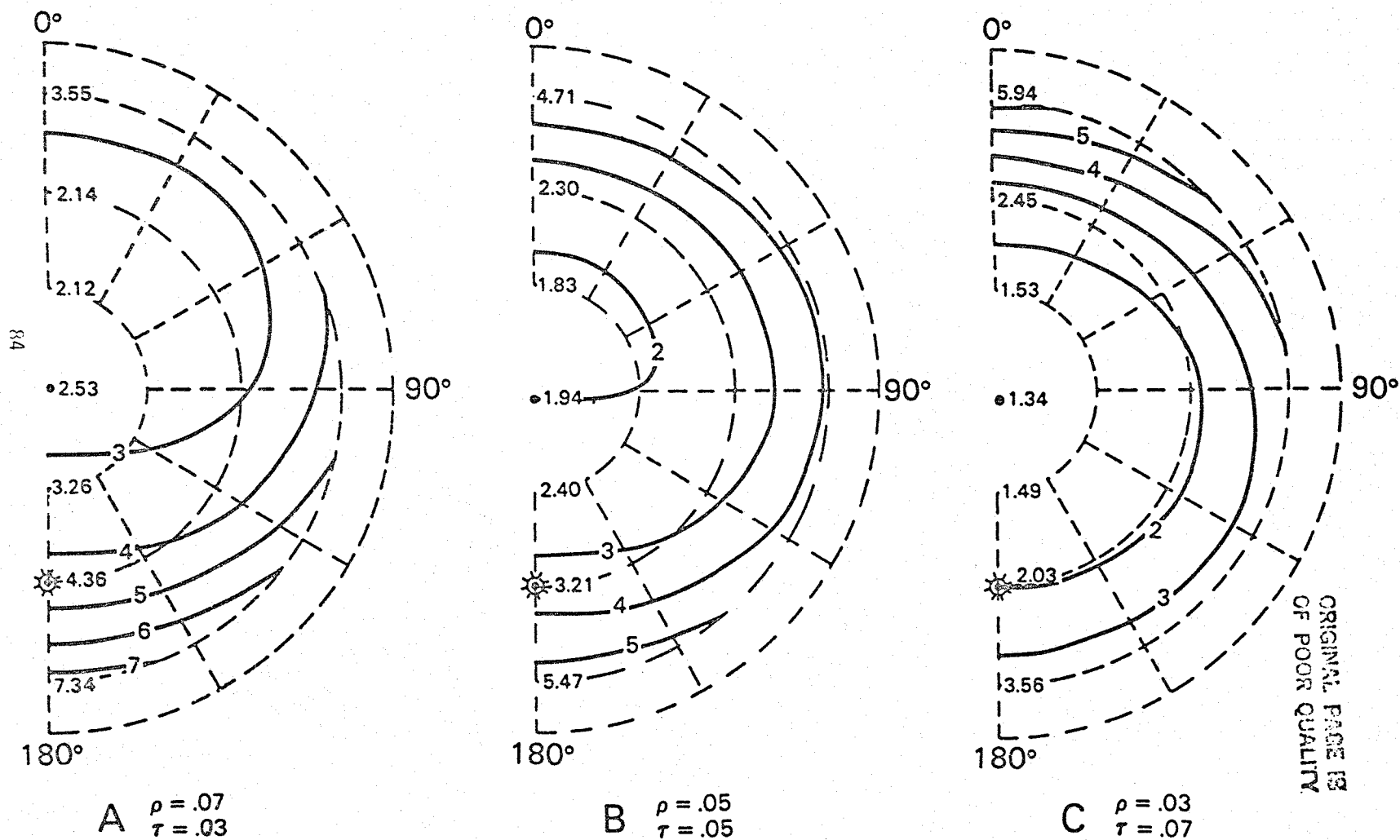
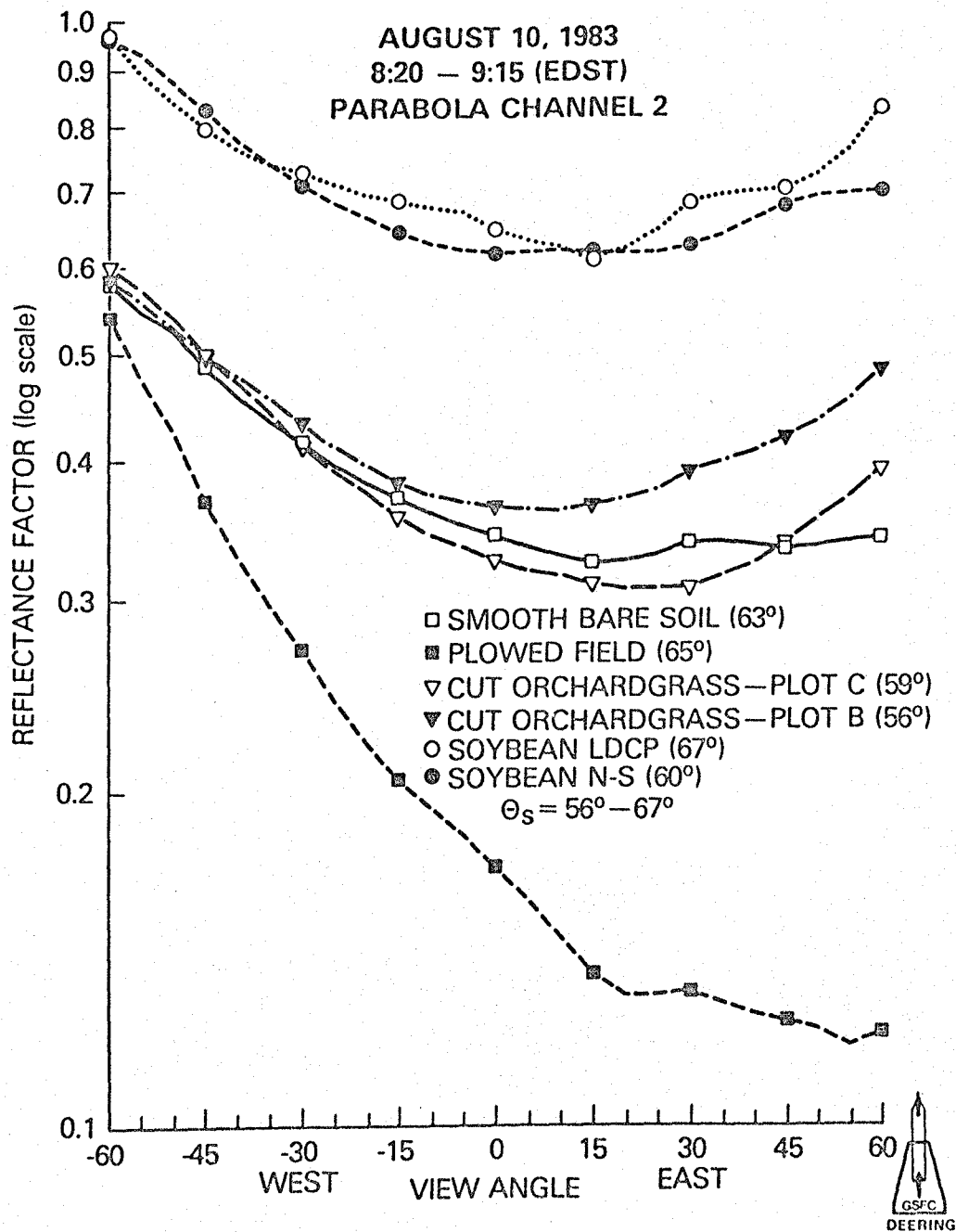


Fig. 11

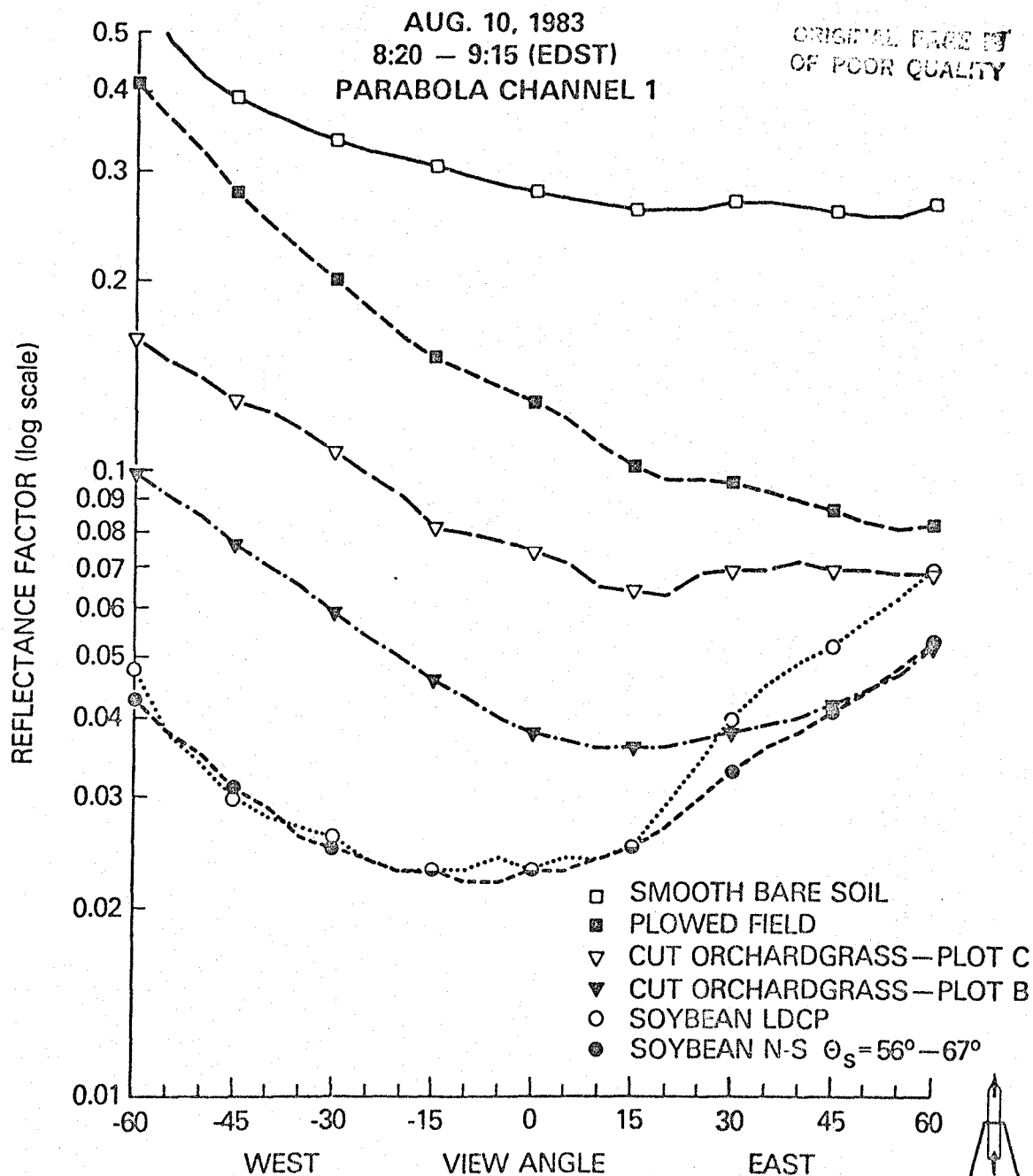


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# PRINCIPAL PLANE REFLECTANCES AT $0.862 \mu\text{m}$ FOR THREE SURFACE TYPES AND TWO VARIATIONS OF EACH



# PRINCIPAL PLANE REFLECTANCES AT $0.662\mu\text{m}$ FOR THREE SURFACE TYPES AND TWO VARIATIONS OF EACH



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## MEASUREMENT AND MODELING OF THE OPTICAL SCATTERING PROPERTIES OF CROP CANOPIES

V. Vanderbilt and L. Grant

### INVESTIGATION SYNOPSIS

#### A. Broad Goals and Investigation Objectives

- \* to measure, analyze, and mathematically model the specular, polarized, and diffuse light-scattering properties of several plant canopies and their component parts (leaves, stems, fruit, soil) as a function of view and illumination angles and to make available to the remote sensing community these data and the necessary ancillary data for evaluating light-canopy interaction models.
- \* to evaluate the potential of these light-scattering properties for ground cover discrimination and condition assessment.
- \* to investigate these properties both in the laboratory and in the field and the effect on them of a disturbing atmosphere.

#### B. First Year Objectives

- \* Introduce and demonstrate the new technique for determining specular, polarized, and diffuse components of the reflectance factor of plant canopies.
- \* Measure (1) the polarized light-scattering characteristics and (2) the necessary ancillary data of plant canopies and begin preparation of data sets for use by ourselves and other investigators developing and testing light-canopy interaction models.
- \* Design and construct a completely new optical instrument system, a portable polarization photometer capable of acquiring and digitally storing the data needed to determine the reflectance factor  $R(55,0;55,180)$  of a leaf surface
  - in vivo (in the laboratory or field)
  - at six wavelengths in the visible and near infrared at two polarizations
  - illuminated and viewed at Brewster angle.

- \* Using polarization photometer, determine the mean and standard deviation of the polarized/diffuse/specular components of reflectance factor of leaves.
  - in a survey of plant species and varieties representing crops, forests, "weeds," and horticulture, including as factors (when appropriate) leaf pigmentation, development stage, position of leaf on plant, and position of instrument on leaf
  - of a corn canopy as a function of its moisture stress
  - of a greenhouse-grown wheat inoculated with wheat rust.
- \* Encourage other investigators to join in examining the specular/diffuse/polarized light-scattering characteristics of leaves and plant canopies.

#### C. Technical Progress and Accomplishments

- \* Analysis of in-house polarization, sun/view angle data set of wheat completed.
- \* Polarization photometer instrument system completed.
- \* Survey of light-polarization properties (measured with polarization photometer) of individual plant leaves initiated. Twenty-two species/varieties were measured before frost.
- \* The light-polarizing properties of both moisture-stressed corn leaves and diseased wheat leaves (inoculated with wheat rust) were measured.
- \* Sun/view angle data plus ancillary data (necessary to support testing of light-canopy interaction models) were acquired on two wheat canopies on two dates and on one sorghum canopy on two adjacent days.

#### D. Results/Scientific Findings

- \* Specular portion of reflected light was found to be 50% of the total light reflected by a wheat canopy.
- \* Specular and diffuse portions of leaf reflectance factor at Brewster angle vary significantly with species, from leaves being almost totally diffuse to almost totally specular (85% specular for corn).
- \* Specular portion of leaf reflectance factor is possibly a major source of variation -- noise -- in the reflectance of individual leaves from one species or variety.
- \* Leaf surface specular reflection does not depend on sub-surface leaf pigmentation.
- \* Relative water content of moisture-stressed corn was found to be inversely and linearly related to the diffuse portion of the leaf reflectance factor in the red wavelength region.
- \* The severity of wheat rust (no. of uredinia per unit leaf surface area) is linearly related to the specular portion of the leaf reflectance factor.

#### E. Significance to General Research Area

- \* These results show that the leaves of many plants are moderately good specular reflectors. To correctly model the light-canopy interaction for fields of such plants, we must specifically consider the specular component of the scattered light.
- \* These results show there is information in the separate parts of the leaf reflectance -- specular (dependent on leaf surface properties) and diffuse (dependent on leaf bulk properties, including chlorophyll activity).
- \* These results suggest that a linear transformation of the Landsat bands might be correlated with moisture stress in corn and that an entirely different transformation of the Landsat bands might be correlated with disease infestations of rust in wheat.
- \* These results suggest it is virtually impossible to separate for most species the specular and diffuse com-

ponents of leaf reflectance using a Beckman DK2-type instrument with integrating sphere.

F. Relationship to Other SRAEC Investigations

- \* We have acquired wheat and sorghum data sets for supporting development and testing of light-canopy interaction models.

G. Second Year Objectives

- \* Acquire additional sun/view angle data of the polarized light-scattering properties of plant canopies. This effort will continue support for development and testing of light-canopy interaction models.
- \* Investigate the polarized light-scattering properties of ground cover measured through a disturbing atmosphere. Collaborate with an atmospheric scientist to extend these results with the aid of a computer-based atmospheric model.
- \* Continue to search for and investigate spectral light-scattering properties indicative of canopy condition (such as the corn moisture content and severity of wheat rust).
- \* Perform an ANOVA type of statistical experiment using carefully cultivated plots at the Purdue Agronomy Farm to investigate the potential information in specular/polarized/diffuse components of the canopy reflectance factor.
- \* Investigate more thoroughly sources of variation in specular and diffuse reflection and relate them to surface and anatomical features of leaf.
- \* Investigate importance of Rayleigh and Mie scattering.
- \* Study light-scattering properties of leaves as a function of angle.

#### H. Study Participants and Affiliations

V.C. Vanderbilt	Principal Investigator
C.S.T. Daughtry	Ph.D. Collaborator
L.L. Biehl	M.S. Collaborator
L. Grant	Ph.D. Graduate Student
H. White	Undergraduate Technician
D. Duncan	Undergraduate Programmer
G. Shaner	Unpaid Ph.D. Collaborator

#### I. Publications

Vanderbilt, V.C., L. Grant, L.L. Biehl, and B.F. Robinson. Specular, diffuse and polarized light scattered by two wheat canopies. Accepted by Applied Optics.

Vanderbilt, V.C. Measuring plant canopy structure. Submitted to Photogrammetric Engineering and Remote Sensing.

Vanderbilt, V.C., and L. Grant. Light polarization measurements: a method to determine the specular and diffuse light-scattering properties of both leaves and plant canopies. Conference paper presented to the International Colloquium on Spectral Signatures of Objects in Remote Sensing, September 1983, Bordeaux, France. LARS Technical Report 091683.

Grant, L., V.C. Vanderbilt, and C.S.T. Daughtry. 1983. Measurements of specularly reflected radiation for individual leaves. Agronomy Abstracts 75:12.

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## REFLECTANCE MODELING

A. Strahler  
Hunter College

### INVESTIGATION SYNOPSIS

#### A. BROAD GOALS AND INVESTIGATION OBJECTIVES

- GENERAL UNDERSTANDING OF BRDF (BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION)
- DEVELOP AND EXTEND BRDF MODELS FOR HETEROGENEOUS CANOPIES OF PARTIAL COVER
  - ESPECIALLY PROCESS-ORIENTED MODELS DRIVEN BY PHYSICAL PARAMETERS AND MEASUREMENTS

#### B. FIRST-YEAR OBJECTIVES

- MODIFY INVERTIBLE CONIFEROUS FOREST CANOPY REFLECTANCE MODEL TO ACCOMODATE OVERLAPPING OF CROWNS AND SHADOWS
- COLLECT AND ANALYZE PHOTOGRAPHIC DATA TO CALIBRATE TREE SPACING FUNCTIONS
- CARRY OUT FIELD WORK TO PARAMETERIZE SPACING, HEIGHT, AND SHAPE OF CONIFERS IN OPEN AND CLOSED STANDS

*over  
p. 100*

## C. TECHNICAL PROGRESS AND ACCOMPLISHMENTS

## D. RESULTS/SCIENTIFIC FINDINGS

- EXTENSION OF MODEL TO MORE DENSELY STOCKED STANDS
  - DEVELOPMENT OF LINEAR APPROXIMATION TO OVERLAPPING FUNCTION
  - TESTING WITH MONTE CARLO SIMULATION MODEL SHOWS HIGH ACCURACY WITH MEAN, PROBLEMS WITH VARIANCE
- ANALYSIS OF SPACING FUNCTION USING AIR PHOTOS
  - MANUAL DIGITIZATION OF LOCATION OF TREES IN SIX PLOTS REPRESENTING STANDS OF DIFFERENT DENSITIES
  - ANALYSIS OF LOCATIONS WITH RESPECT TO POINT PATTERN MODELS
  - RESULTS: QUADRAT SIZES 10-50 m, POISSON OK. AT SIZES >50m, PROBABLY CLUMPED. BELOW 10 m, TENDS TO UNIFORM.
- FIELD WORK
  - DATA NEEDED TO SPECIFY SPACING FUNCTION, HEIGHT DISTRIBUTION, AND SHAPE OF TREES
  - CHOSE THREE STANDS REPRESENTATIVE OF REGIONAL CONIFER FOREST: OPEN PONDEROSA PINE; THINNED PONDEROSA PINE WITH SOME WHITE FIR; DENSE, TALL MIXED CONIFER W/ MUCH RED FIR
  - LAID OUT GRID OF CIRCULAR PLOTS IN EACH STAND AND MEASURED DBH, TOOK HEIGHT AND SHAPE MEASUREMENTS.
- FIELD DATA ANALYSIS -- IN PROGRESS
  - FITTING OF HEIGHT, SPACING MODELS
  - EXAMINING EFFECTS OF THINNING, ETC.

#### E. SIGNIFICANCE TO GENERAL RESEARCH AREA

- PROVIDES DIRECT SUPPORT FOR SCENE ANALYSIS, FORESTRY APPLICATION, OTHER MODELING EFFORTS AND MEASUREMENT PROGRAMS
- SUPPORTS PREDICTION OF OPTICAL-REFLECTIVE RESPONSES OF VEGETATION CANOPIES

#### F. RELATION TO OTHER FUNDAMENTAL SRAEC INVESTIGATORS

- DIRECTLY RELATED TO, AND COORDINATED WITH, SMITH, NORMAN
- COULD INCORPORATE/RELATE TO WORK BY TUCKER, VANDERBILT, MOORE

#### G. SECOND-YEAR OBJECTIVES

- EXTEND INVERTIBILITY TO OVERLAPPING CASE
- DEVELOP MODEL/PARAMETERS FOR SPACING FUNCTION, HEIGHT DISTRIBUTION, CANOPY FORM
- CONTINUE MONTE CARLO SIMULATIONS, EXTEND TO FULL THREE DIMENSIONS
- ASSEMBLE, REGISTER MULTIIMAGE DATASET FOR TEST AREA
  - TM SIMULATOR (30 M, 7 BAND)
  - LANDSAT 4 MSS (50 M, 4 BAND)
  - SPOT SIMULATOR (10 M, 3 BAND)
  - JPL AIS (30 M, 128 BAND)
  - DTM (30 M, OPTICAL CORRELATOR)

## H. STUDY PARTICIPANTS AND AFFILIATIONS

### • GRADUATE STUDENTS -- UCSB

- CURTIS E. WOODCOCK (PH.D EXP. 1984)
- XIAOWEN LI (PH.D EXP. 1985)
- JANET FRANKLIN (MA, 1983)

### • COLLABORATORS

- D. S. SIMONETT, UCSB (SUBCONTRACT)
- J. A. SMITH, CSU
- J. M. NORMAN, U. NEB.

## I. PUBLICATIONS

### THESES:

FRANKLIN, JANET, 1983, AN EMPIRICAL STUDY OF THE SPATIAL PATTERN OF CONIFEROUS TREES. M.A. THESIS, UNIV. OF CALIF., SANTA BARBARA

### MANUSCRIPTS IN PROGRESS:

FRANKLIN, J., J. MICHAELSON, AND A. STRAHLER, A COMPARISON OF STATISTICAL METHODS FOR MEASURING SCALE DEPENDENT PATTERN IN FOREST STANDS. IN SECOND DRAFT.

STRAHLER, A., AND X. LI, SPATIAL/SPECTRAL MODELING OF DISCONTINUOUS CONIFER STANDS. FIRST DRAFT ABOUT HALF COMPLETE.

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A STUDY OF THE RELATION BETWEEN CROP GROWTH  
AND SPECTRA REFLECTANCE PARAMETERS

*G. Badhwar*  
G. Badhwar  
NASA/JSC

INVESTIGATION SYNOPSIS

A. BROAD GOALS AND INVESTIGATION OBJECTIVES

- o To INVESTIGATE THE DYNAMIC BEHAVIOR OF CANOPY REFLECTANCE VERSUS TIME AND THE RELATIONSHIP THAT SUCH TRAJECTORIES BEAR TO CANOPY DYNAMICS, FOR EXAMPLE, ONTOGENY AND MORPHOLOGY.
- o To UNDERSTAND WHICH TRANSFORMATIONS OF SPECTRAL DATA ARE BEST SUITED FOR OBSERVING KEY CANOPY CHARACTERISTICS, SUCH AS LEAF AREA INDEX AND VEGETATION IDENTIFICATION.
- o To FORMULATE A PHYSICAL BASIS FOR UNDERSTANDING HOW VARIOUS SPECTRAL TRANSFORM TRAJECTORIES DEPEND ON VEGETATION TYPE AND FORMULATE MODELS THAT DESCRIBE THE TIME DELAYED INTERACTION OF REFLECTANCE IN THE CHLOROPHYLL AND WATER ABSORPTION BANDS TO MONITOR STRESS.
- o AS PART OF THE GENERAL PROCESS OF PHYSICAL UNDERSTANDING OF CANOPY REFLECTANCE, EVALUATE AND IMPROVE EXISTING CANOPY MODELS.

B. FIRST YEAR OBJECTIVES

- o To INVESTIGATE THE DYNAMIC BEHAVIOUR OF CANOPY REFLECTANCE VERSUS TIME AND THE RELATIONSHIP THAT SUCH TRAJECTORIES BEAR TO CANOPY DYNAMICS, FOR EXAMPLE, ONTOGENY AND MORPHOLOGY.
- o To FORMULATE PHYSICAL BASIS FOR UNDERSTANDING HOW VARIOUS SPECTRAL TRANSFORM TRAJECTORIES DEPEND ON VEGETATION TYPE.

### C. TECHNICAL PROGRESS AND ACCOMPLISHMENT

- o A DIFFERENTIAL EQUATION DESCRIBING THE TEMPORAL BEHAVIOR OF GREENNESS WITH TIME WAS DEVELOPED AND SHOWN TO FIT THE OBSERVATIONS VERY WELL.
- o IT PROVIDED:
  - A TECHNIQUE TO ESTIMATE LEAF AREA INDEX
  - A WAY TO ESTIMATE KEY ONTOGENIC STAGE OF CROPS
  - PARAMETERS TO IDENTIFY AND SEPARATE VARIOUS CROPS
- o THESE PARAMETERS WERE SHOWN TO BE STABLE OVER VAST AREA OF UNITED STATES AND FOR THE FIRST TIME OVER A FOREIGN COUNTRY (ARGENTINA).
- o SCATTERING BY ARBITRARILY INCLINED LEAVES (SAIL) MAULTILAYER MODEL WAS IMPLEMENTED AND TESTED OVER CORN AND SOYBEAN CROPS.
- o SERIOUS LIMITATION OF SUITS, SAIL AND CUPID MODEL OVER THESE DATA SETS HAVE BEEN FOUND. IMPROVEMENTS HAVE BEEN SUGGESTED.

### D. RESULTS/SCIENTIFIC FINDINGS

- o DYNAMIC BEHAVIOR OF GREENNESS,  $G(t)$ , IS DESCRIBED BY
$$\frac{dG(t)}{dt} = k(t) \left(1 - \frac{G}{G_M}\right)$$
WHERE  $G_M$  IS THE MAXIMUM GREENNESS AT TIME  $T_P$ .
- o IT HAS BEEN DEMONSTRATED THAT  $k(t)$  OBEYS THE LAW
$$k(t) = 2 \left[1/t + 1/T_P - t\right] \quad t < T_P$$
- o AND  $\int k(t)dt$  IS LINEARLY PROPORTIONAL TO LEAF AREA INDEX
- o MAXIMUM GREENNESS,  $G_M$ , TIME OF MAXIMUM GREENNESS,  $T_P$ , AND PROFILE WIDTH,  $\sigma$ , ARE THE KEY VARIABLE THAT RETAIN NEARLY ALL THE INFORMATION IN RAW CHANNELS ARE STABLE OVER VAST GEOGRAPHIC AREAS, AND ARE PREDICATABLE.
- o THE TIME OF PEAK AND INFLECTION CAN PROVIDE KEY ONTOGENIC STAGES.

E. SIGNIFICANCE TO GENERAL RESEARCH AREA

- o BIOPHYSICAL CHARACTERISTICS ESTIMATION
- o OPTICAL MODELING OF CANOPY REFLECTANCE.

F. RELATIONSHIP TO OTHER FUNDAMENTAL RESEARCH INVESTIGATIONS

- o PROVIDES KEY INPUT TO OPTICAL REFLECTANCE MODELING.
- o PROVIDES INTERPRETATION OF REFLECTANCE.
- o DERIVED PARAMETER  $G_M$ ,  $T_P$  AND  $\sigma$  HAVE FOUND THERE WAY IN MANY FUNDAMENTAL RESEARCH INVESTIGATIONS OF MPRIA.

G. SECOND YEAR OBJECTIVES

- o VERIFY THE VALIDITY OF CANOPY REFLECTANCE MODELS AND MODIFY THEM TO CORRECT FOR DEFICIENCIES.
- o UNDERSTAND WHY THE PEAK GREENNESS FOR SOYBEAN IS GREATER THAN FOR CORN USING THESE MODELS? ARE THERE CONDITIONS UNDER WHICH THIS IS NOT VALID?
- o MATHEMATICALLY FORMULATE THE KEY PROBLEM OF FINDING OPTIMUM TRANSFORMATIONS, BASED ON VERIFIED CANOPY MODELS, THAT MAXIMIZE THE SENSITIVITY TO LEAF AREA INDEX AND MINIMIZE SENSITIVITY TO ALL THE OTHER VARIABLES.
- o APPLY THESE TRANSFORMATIONS TO WHEAT, BARLEY, OATS, CORN AND SOYBEAN CROPS.

H. STUDY PARTICIPANTS

1. JERRY KRANTZ
2. MARY ANN TOMPKINS
3. LYNNE ALEXANDER
4. DR. SYLIVA SHEN

ALL OF LOCKHEED MSCO, HOUSTON, TEXAS 77058



## I. PUBLICATIONS

BADHWAR, G. D., (1984): AUTOMATIC CLASSIFICATION OF CORN AND SOYBEAN USING LANDSAT DATA: PART I: NEAR-HARVEST CROP PROPORTION ESTIMATION. REMOTE SENSING OF ENVIRONMENT, FEBRUARY (1984)

BADHWAR, G. D., (1984): AUTOMATIC CLASSIFICATION OF CORN AND SOYBEAN USING LANDSAT DATA: PART II: EARLY-SEASON CROP PROPORTION ESTIMATION. REMOTE SENSING OF ENVIRONMENT, FEBRUARY (1984)

HENDERSON, K. E. AND G. D. BADHWAR (1984): AN INITIAL MODEL FOR ESTIMATING DEVELOPMENT STAGES FROM SPECTRAL DATA. REMOTE SENSING OF ENVIRONMENT, FEBRUARY (1984)

G. D. BADHWAR (1984) - USE OF LANDSAT-DERIVED PROFILE FEATURES FOR SPRING SMALL GRAINS CLASSIFICATION, INTERNATIONAL JOURNAL OF REMOTE SENSING, (1984)

D. HELMER, J. KRANTZ, M. TOMPKINS, AND G. D. BADHWAR (1983) - USER GUIDE FOR THE EXTRACTION OF LANDSAT SPECTRAL AND AGRONOMIC DATA, AgRISTARS DOCUMENT JSC-18598

D. HELMER, J. KRANTZ, M. KINSLER, M. TOMPKINS, AND G. D. BADHWAR (1983) COMPOSITION AND ASSEMBLY OF A SPECTRAL AND AGRONOMIC DATA BASE FOR 1980 SPRING SMALL GRAIN SEGMENTS, AgRISTARS DOCUMENT JSC-18593

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LYNNE ALEXANDER AND G. D. BADHWAR (1983) - SAIL CANOPY MODEL FORTRAN SOFTWARE, LEMSCO-19867

## MODEL

o Models indicate that:

+ The dominant contributor to the reflective signal is leaves

+ The Key parameter is the leaf area index (one-sided leaf area)

o  $K(t)$ : Time rate of change of LAI

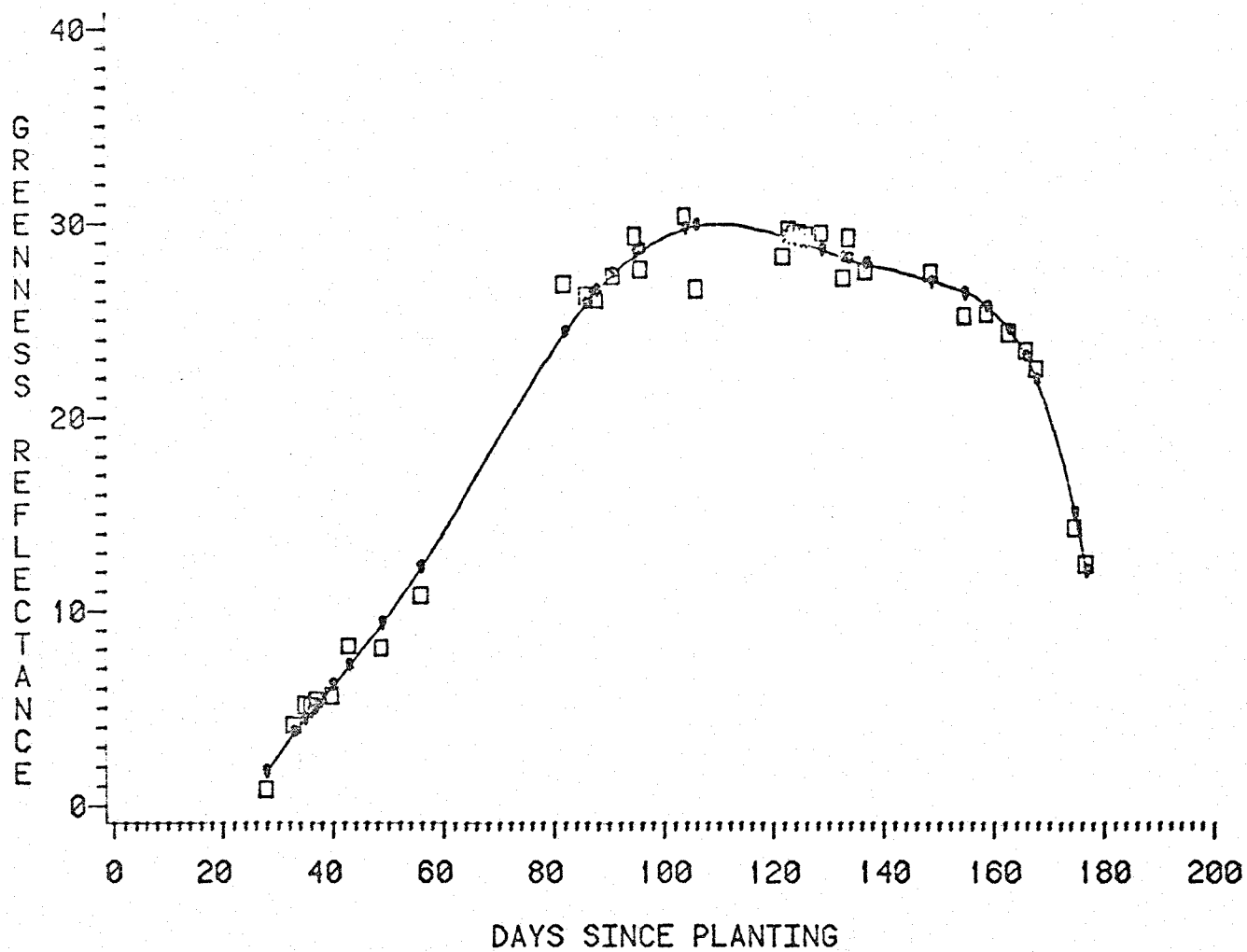
$$o \quad \frac{d\rho(t)}{dt} = K(t)\rho \left(1 - \frac{\rho(t)}{\rho_m}\right)$$

$\rho$  = greenness

$\rho_m$  = maximum value of greenness attained at time  $t=t_p$

$$o \quad \int K(t)dt \propto \text{Leaf Area Index}$$

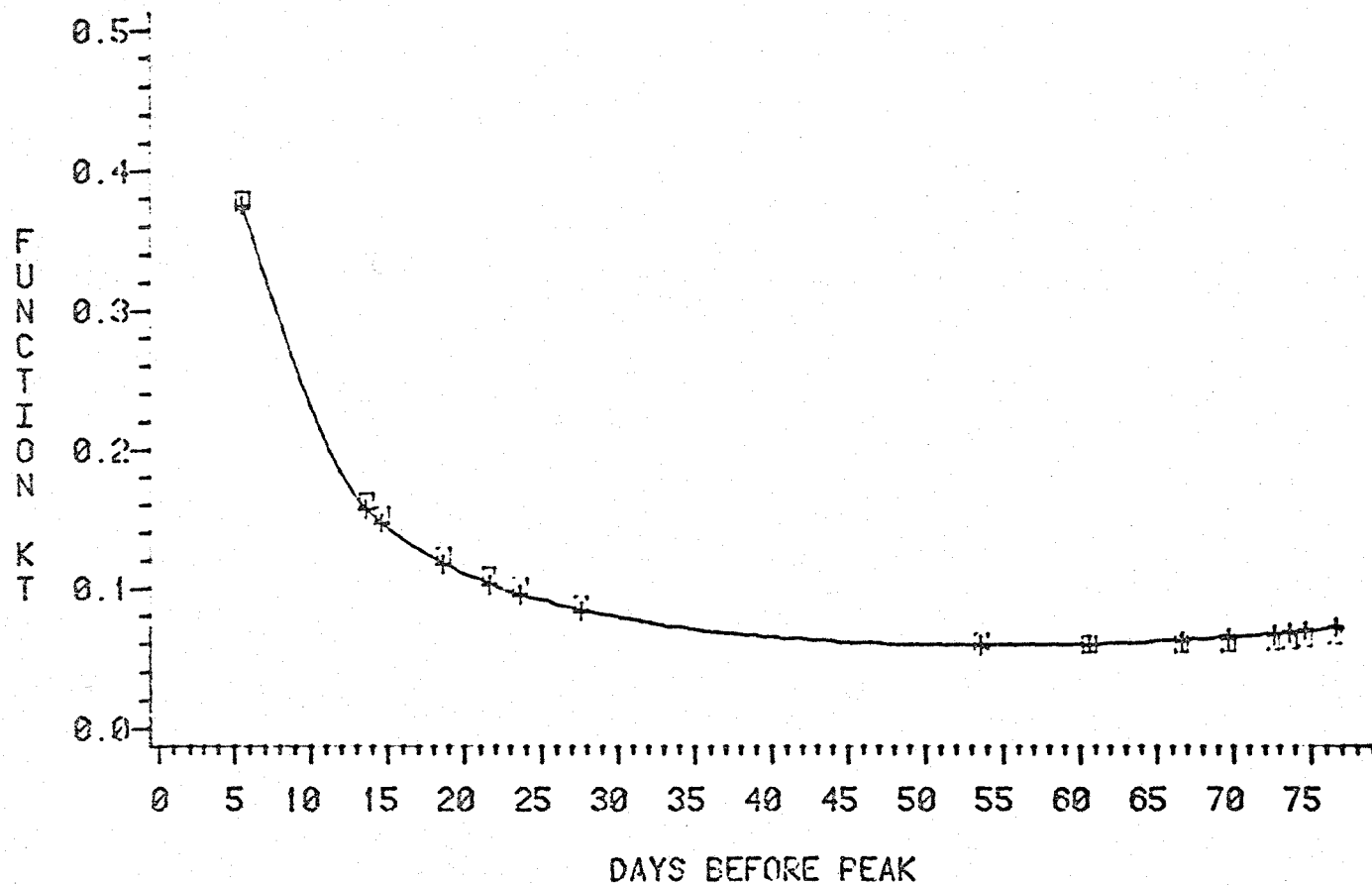
ORIGINAL PRICE IS  
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PLOTS 1A WHEAT (ARIZONA)

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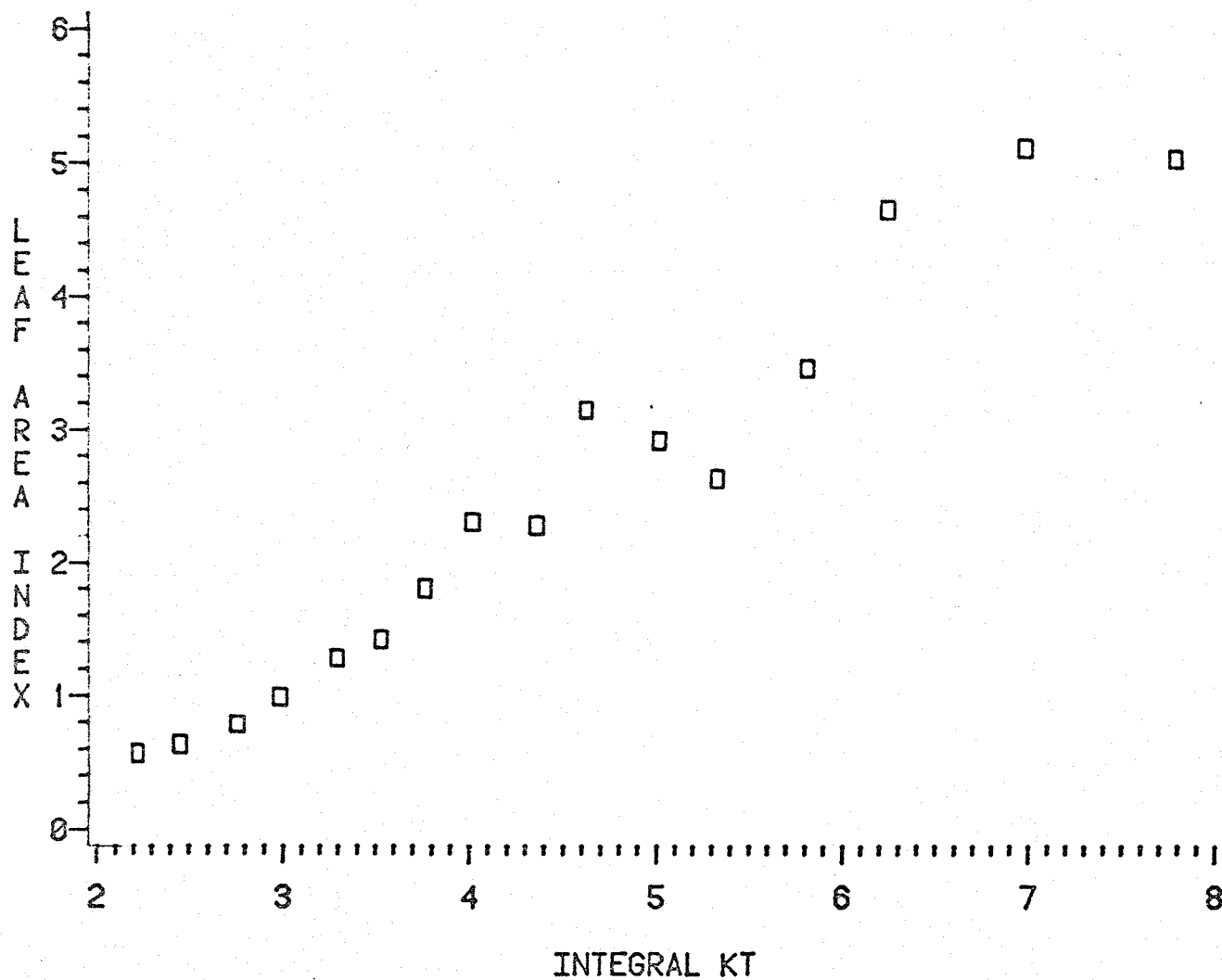
$$\text{MODEL} = (\text{TP} \{2./(\text{TP}-\text{T})\})/\text{T}$$



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PLOTS 1A WHEAT(CARIZONA)  
GMAXT = 110.5 GMAX = 32.1975 R-SQUARE = 0.989748

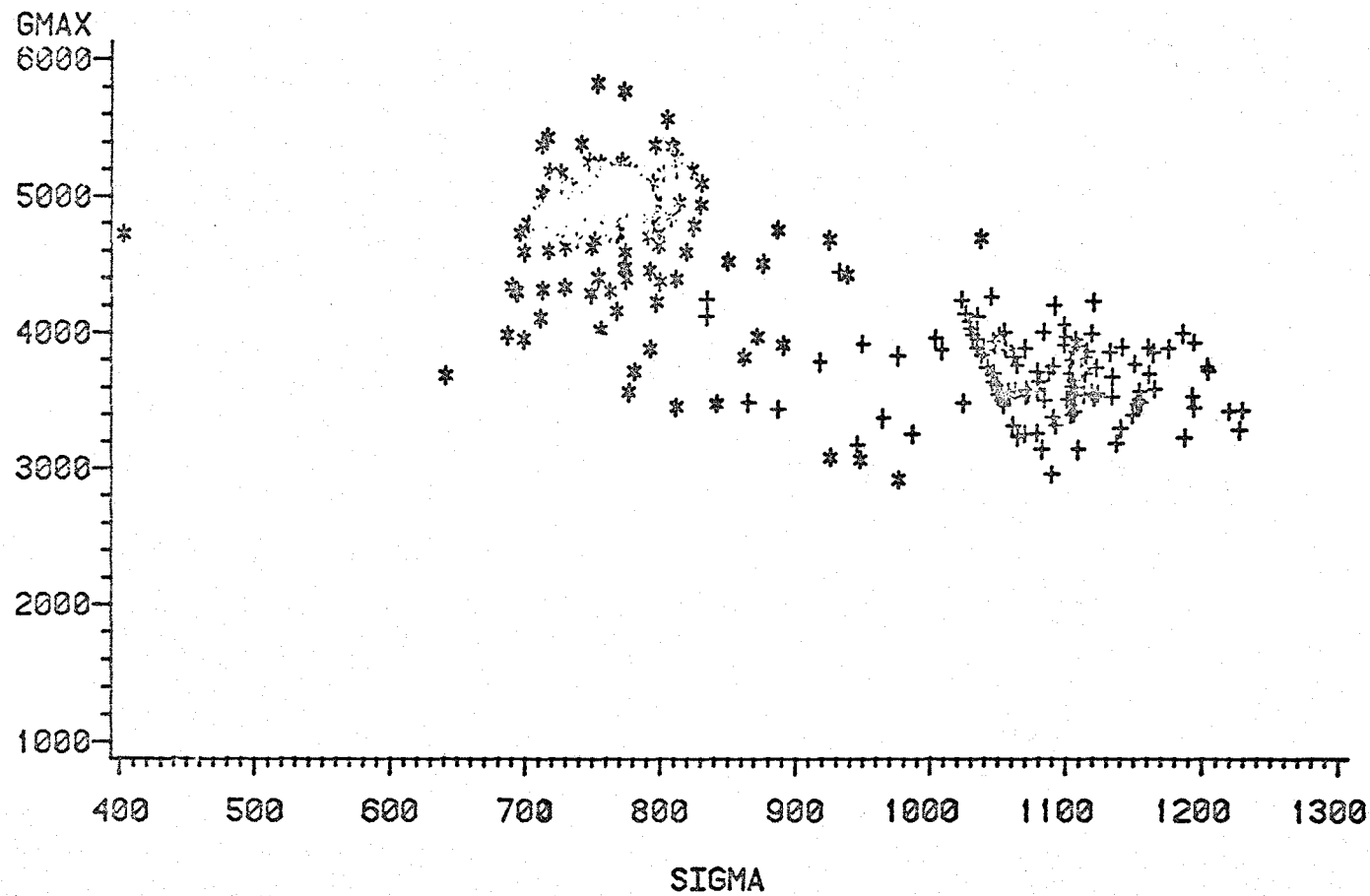
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DAYS BEFORE PEAK  
PLOTS 1B WHEAT (ARIZONA)

GMAXT = 105.9 MAX = 185 B0 = 0.1169147 B1 = -2 B2 = 9.978696

# CORN SOYBEAN



LEGEND: GTLAB    + + + 1    \* \* \* 2

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62-1079 (1/1)

### III.C.2. SCENE RADIATION STUDIES-MICROWAVE REGIME

- A. Fung - Scattering Models in the Microwave Regime
- J. Kong - Remote Sensing of Earth Terrain
- R. Lang - Discrete Random Media Techniques for Microwave Modeling of Vegetated Terrain
- F. Ulaby - Measuring and Modeling of the Dielectric Properties and Attenuation of Vegetation
- R. Moore - Determination of the Sources of Radar Scattering
- J. Paris - Microwave Backscattering Properties of Crops

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SCATTERING MODELS IN THE MICROWAVE REGIME

A. Fung  
U. of Kansas

Center for Research

INVESTIGATION SYNOPSIS

a. BROAD GOALS AND INVESTIGATION OBJECTIVES

- ◆ TO DEVELOP SCATTERING MODELS FOR AN  
  
INHOMOGENEOUS MEDIUM,
- ◆ TO DEVELOP SCATTERING MODELS FOR AN  
  
IRREGULAR SURFACE.
- ◆ TO COMBINE VOLUME AND SURFACE SCATTERING  
  
TO OBTAIN USEFUL SCATTERING AND EMISSION  
  
MODELS FOR TERRAINS.
- ◆ TO APPLY THE DEVELOPED MODEL TO THE  
  
INTERPRETATION OF MEASURED DATA AND THE  
  
DESIGN OF FUTURE EXPERIMENTS.

b. FIRST YEAR OBJECTIVES

- DEVELOP A TERRAIN SCATTERING MODEL BY  
COMBINING VOLUME SCATTERING (DUE TO  
VEGETATION OR SNOW, ETC.) WITH ROUGH  
SURFACE SCATTERING (DUE TO ROUGH GROUND  
SURFACE).

c. TECHNICAL PROGRESS AND ACCOMPLISHMENTS

- TERRAIN SCATTERING MODELS HAVE BEEN  
DEVELOPED USING THE RADIATIVE TRANSFER  
METHOD WHICH MAY BE APPLICABLE TO A SNOW  
LAYER OR A VEGETATION LAYER WITH IRREGU-  
LAR BOUNDARIES.

d. RESULTS/SCIENTIFIC FINDINGS

• IN SCATTERING FROM AN INHOMOGENEOUS LAYER

WITH IRREGULAR BOUNDARIES IT IS FOUND:

- (1) ROUGH SURFACE SCATTERING IS IMPORTANT AT NEAR VERTICAL OBSERVATIONS AND HAS THE EFFECT OF ENHANCING CROSS-POLARIZED SCATTERING.
- (2) VOLUME SCATTERING FROM LAYER INHOMOGENEITIES DOMINATES SCATTERING (LIKE AND CROSS) AT LARGE INCIDENCE ANGLES.
- (3) THE MECHANISM OF CROSS-POLARIZED SCATTERING IS MULTIPLE SURFACE/VOLUME SCATTERING.

e. SIGNIFICANCE TO GENERAL RESEARCH AREA

- IN THE PAST, ROUGH SURFACE SCATTERING AND  
  
VOLUME SCATTERING WERE TREATED INDEPEN-  
  
DENTLY AS TWO SEPARATE FIELDS OF STUDY.  
  
THIS RESEARCH COMBINES THE TECHNIQUES IN  
  
THE TWO AREAS TO PROVIDE A MORE REALISTIC  
  
TERRAIN SCATTERING MODEL AND PERMITS THE  
  
STUDY OF THE INTERACTION BETWEEN SURFACE  
  
AND VOLUME SCATTERING.

f. RELATIONSHIP TO OTHER FUNDAMENTAL RESEARCH

SRAEC INVESTIGATIONS

RESULTS OF THIS RESEARCH ARE USEFUL FOR  
UNDERSTANDING EXPERIMENTAL OBSERVATIONS  
OF WAVE SCATTERING FROM TERRAINS AND  
PROVIDE INPUT TO THE DESIGN OF FUTURE  
EXPERIMENTS ON TERRAIN SCATTERING.

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g. SECOND YEAR OBJECTIVES

- DEVELOP A SCATTERING MODEL FOR A LAYER OF  
RANDOMLY ORIENTED CIRCULAR DISCS WITH  
RADII COMPARABLE TO THE ELECTROMAGNETIC  
WAVELENGTH. USE THIS MODEL TO INVESTI-  
GATE THE RELATIVE MERITS BETWEEN ACTIVE  
VERSUS PASSIVE SENSING OF SOIL MOISTURE  
OVER VEGETATION-COVERED SOIL SURFACES.

h. STUDY PARTICIPANTS

M. KARAM, GRADUATE STUDENT

G. W. PAN, GRADUATE STUDENT

H. J. EOM, RESEARCH ASSOCIATE

i. PUBLICATIONS (SRAEC SUPPORTED RESEARCH)

Fung, A. K. and H. J. Eom, "Effects of a Rough  
Boundary Surface on Polarization of the  
Scattered Field from an Inhomogeneous  
Medium," IEEE Geoscience and Remote  
Sensing, (IGARSS'82), vol. AP-21, no. 3,  
pp. 265-270, July 1983.

Karam, M. and A. K. Fung, "Scattering from  
Randomly Oriented Circular Discs with  
Application to Vegetation," Radio  
Science, vol. 18, no. 4, pp. 557-565,  
July-August 1983.

Karam, M. and A. K. Fung, "Scattering from Randomly Oriented Scatterers of Arbitrary Shape in the Low-Frequency Limit with Application to Vegetation," Digest of IGARSS'83, IEEE 1983 International Geoscience and Remote Sensing Symposium, August 1983.

Fung, A. K. and H. J. Eom, "Scattering from a Random Layer with Application to Snow, Vegetation and Sea Ice," IEE Proceedings - Special Issue of Radiowave Propagation, (Accepted).

Fung, A. K. and H. J. Eom, "A Scatter Model for Vegetation up to Ku-Band," Remote Sensing of Environment, (Accepted).



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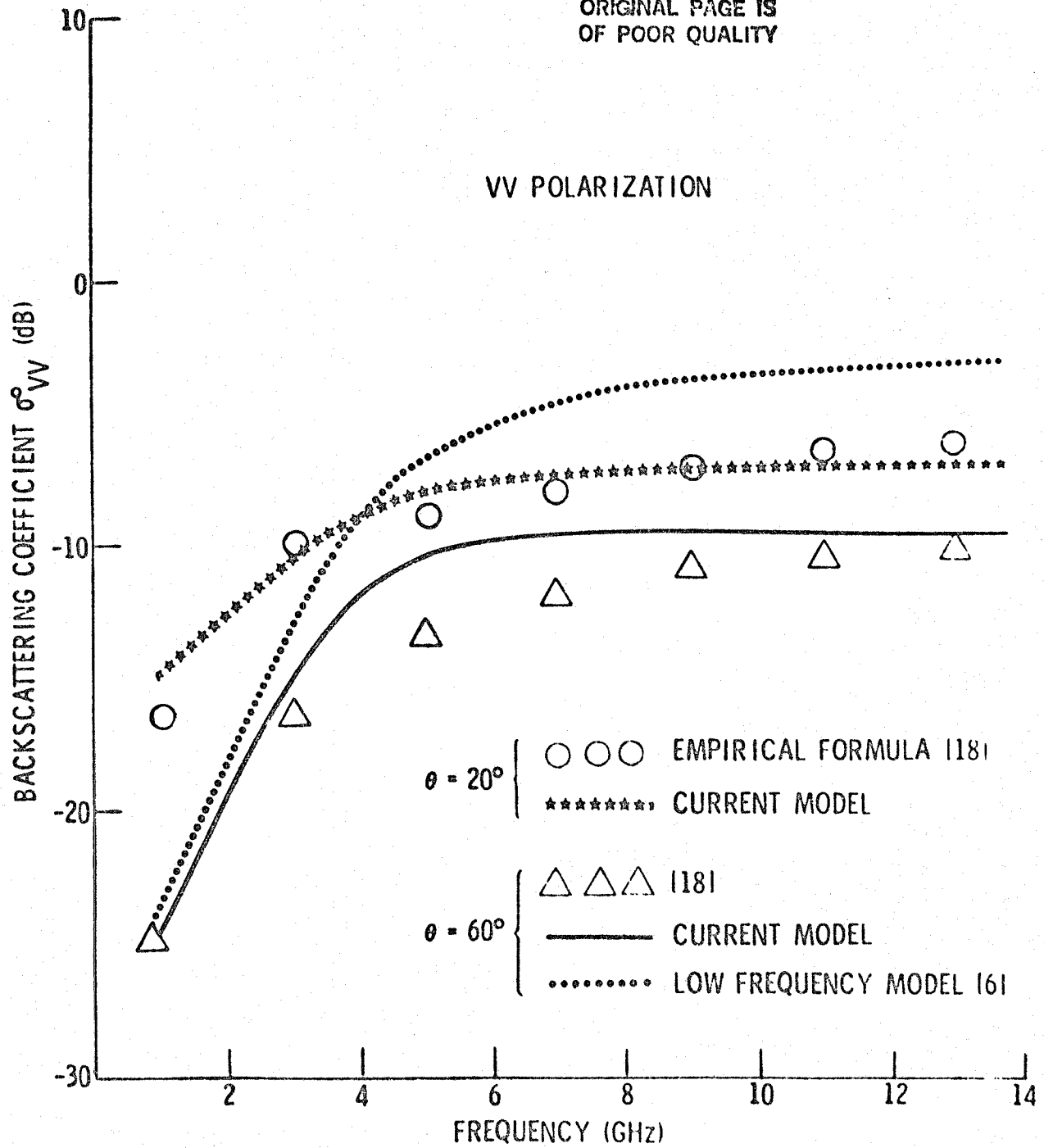
## A NEW VEGETATION SCATTERING MODEL FOR HIGH FREQUENCIES.

THE VEGETATION SCATTERING MODELS IN  
THE PAST WERE FOR LOW FREQUENCY  
APPLICATIONS (FREQ.  $< 3 \text{ GHz}$ )

A VEGETATION SCATTERING MODEL VALID  
UP TO  $14 \text{ GHz}$  HAS BEEN DEVELOPED BY  
EOM AND FUNG<sup>\*</sup>. A COMPARISON  
BETWEEN THIS MODEL AND EARLIER LOW  
FREQUENCY MODEL WITH MEASUREMENTS  
IS SHOWN IN VU-GRAPH (A). 1. VU-  
GRAPH (A)-2, 3 AND 4 SHOW THE COMPARISON  
BETWEEN THIS SCATTERING MODEL AND ANGULAR  
MEASUREMENTS AT 1.1, 4.25 AND 8.6  $\text{GHz}$ .

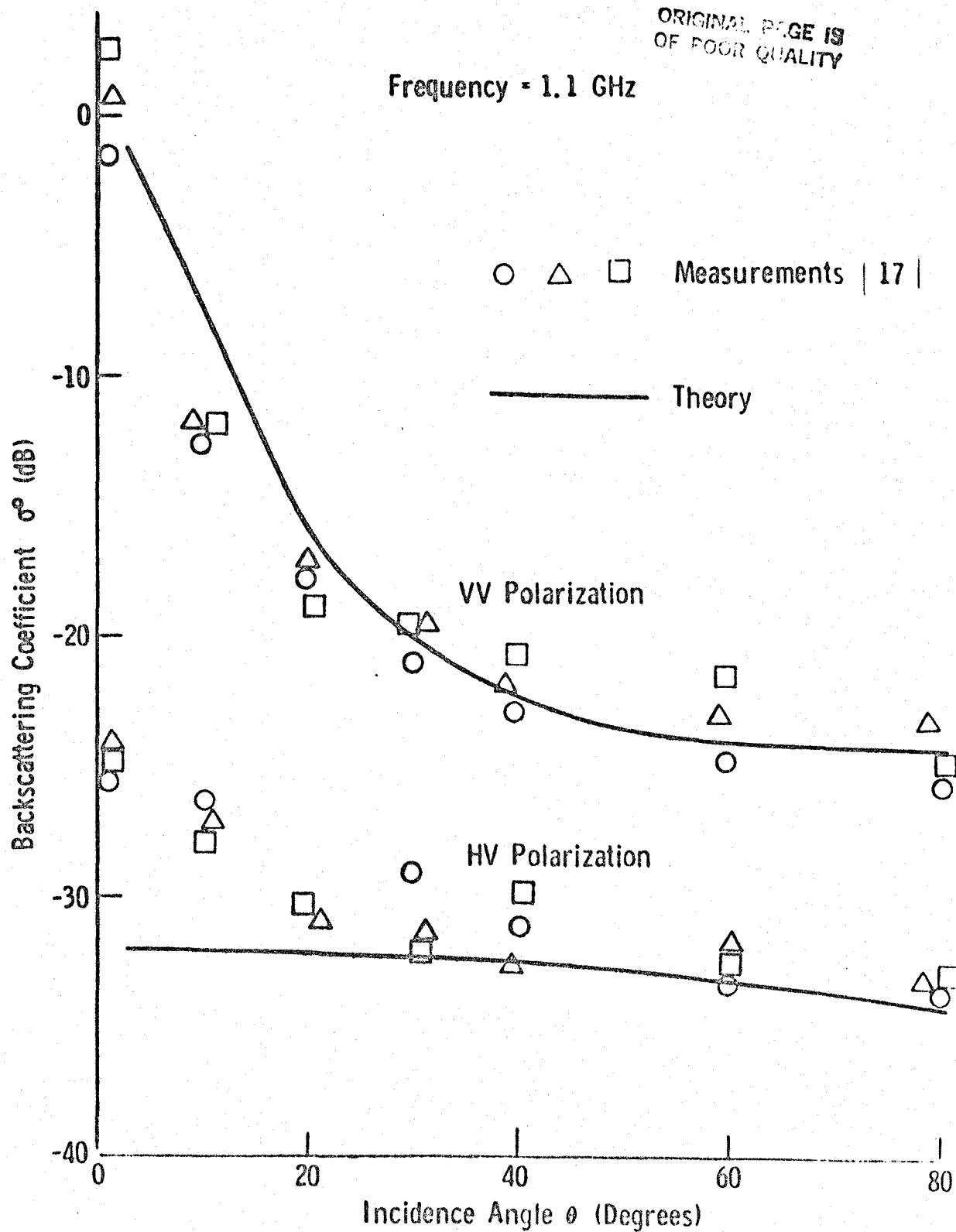
<sup>\*</sup> TO APPEAR IN JOURNAL, REMOTE SENSING  
OF ENVIRONMENT, 1984.

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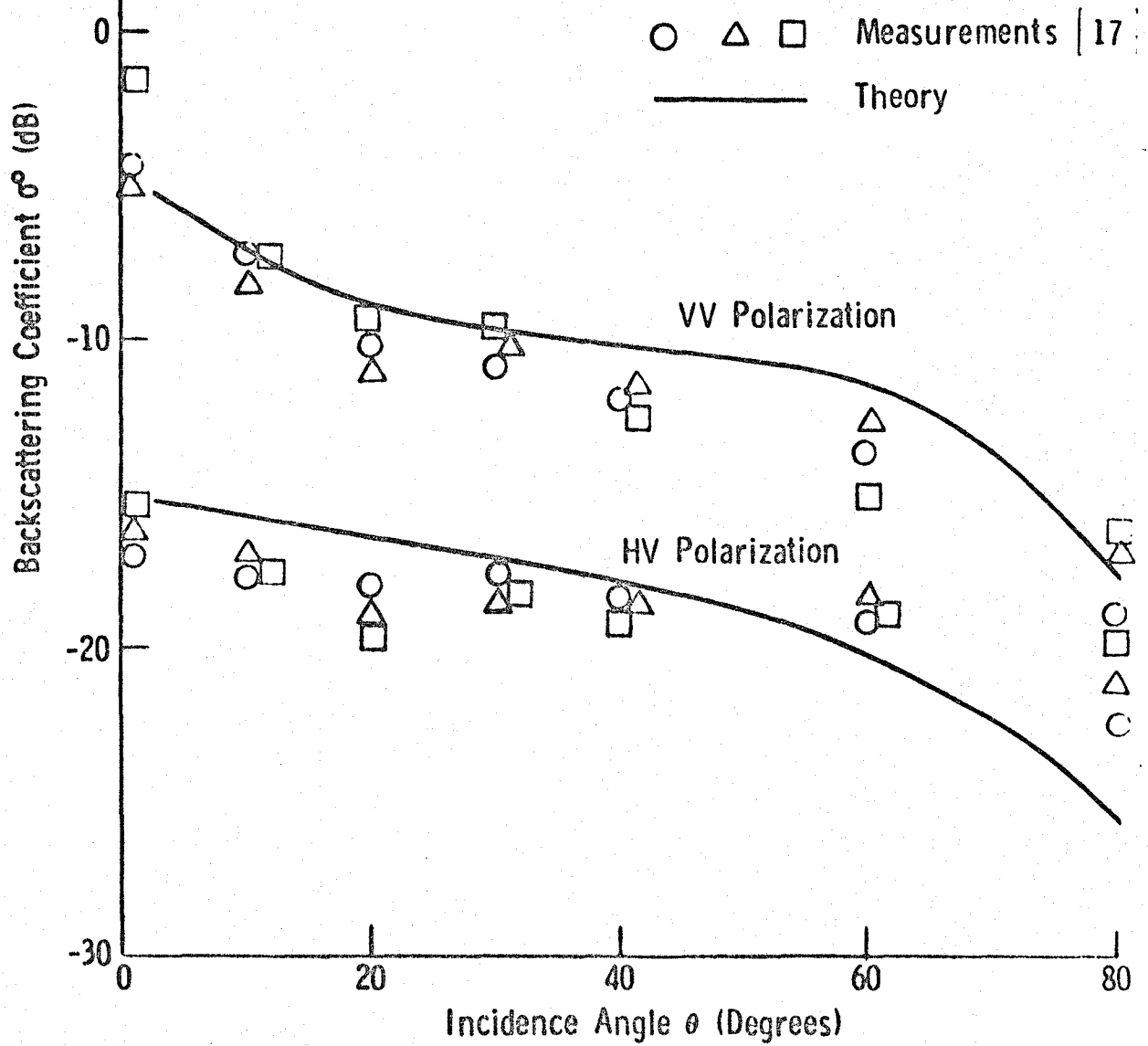
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Frequency = 1.1 GHz



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Frequency = 4.25 GHz



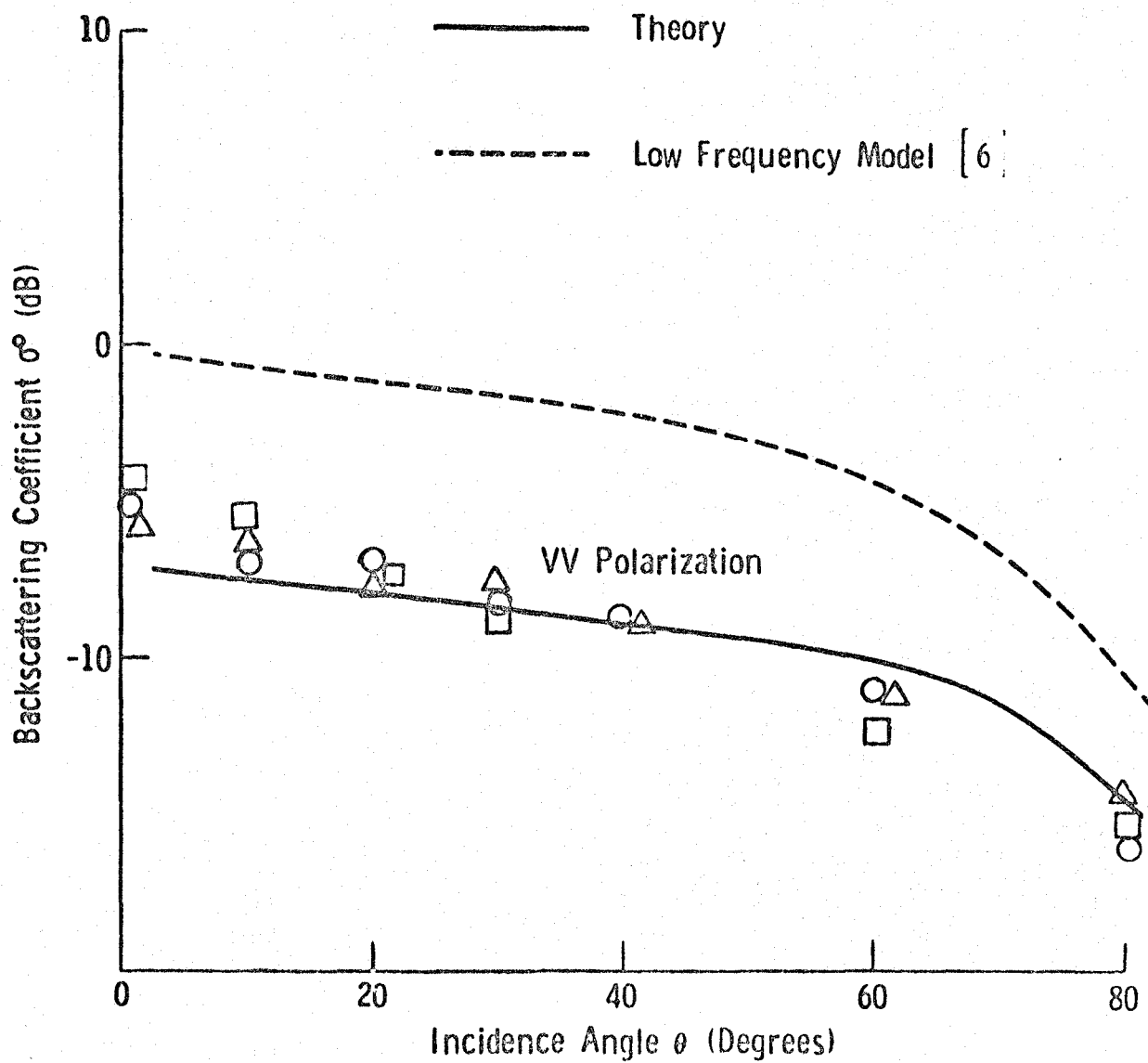
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Frequency = 8.6 GHz

○ △ □ Measurements [17]

— Theory

- - - Low Frequency Model [6]



AN APPLICATION OF THE VEGETATION  
SCATTERING MODEL TO SOIL MOISTURE  
SENSING

WITH A VEGETATION SCATTERING MODEL  
VALID OVER A WIDE RANGE OF FREQUENCIES,  
IT IS NOW POSSIBLE TO USE THIS  
MODEL TO INVESTIGATE THE RELATIVE  
MERIT BETWEEN ACTIVE AND PASSIVE  
SENSING OF SOIL MOISTURE OVER  
VEGETATED TERRAIN. IN VU-GRAPH (B)  
REDUCTION IN SENSITIVITY DUE TO  
VEGETATION COVER IS SHOWN FOR ACTIVE  
SENSING OF SOIL MOISTURE. FOR EXAMPLE,  
AT  $8.6^\circ$  INCIDENCE ANGLE, THE SENSITIVITY  
IS REDUCED TO 0.7 AT AN ALBEDO  
OF 0.3 AND AN OPTICAL DEPTH OF 0.4.  
HERE, SENSITIVITY IS THE CHANGE IN THE  
SCATTERING COEFFICIENT DUE TO CHANGE  
IN SOIL MOISTURE WITH VEGETATION COVER  
TO THAT WITHOUT VEGETATION COVER.

IN VU-GRAPH (C) SIMILAR SENSITIVITY  
CALCULATION IS SHOWN FOR PASSIVE  
SENSING OF SOIL MOISTURE.

UPON COMPARING RESULTS IN VU-GRAPHS  
(B) AND (C) IT IS CONCLUDED THAT ACTIVE  
SENSING IS SUPERIOR TO PASSIVE SENSING  
OF SOIL MOISTURE WHEN THERE IS VEGETATION  
COVER.

# SENSITIVITY REDUCTION IN ACTIVE SENSING OF SOIL MOISTURE OVER VEGETATED AREA

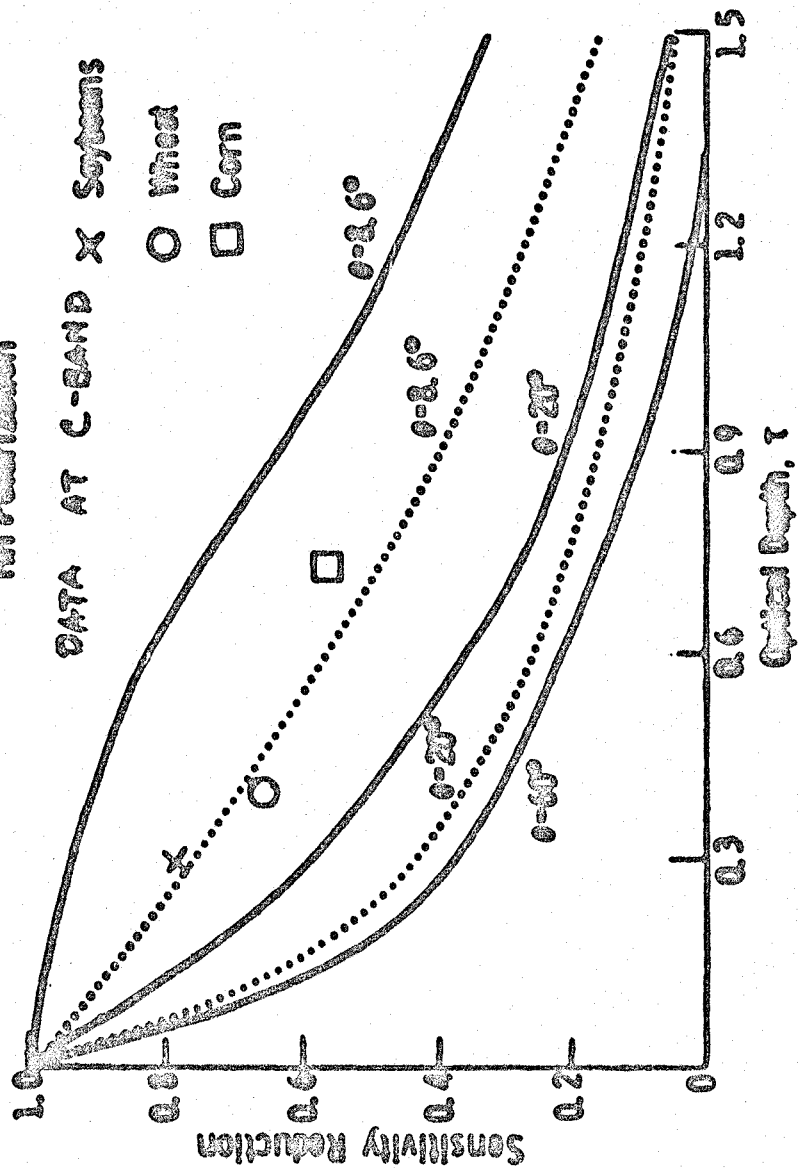
THEORY ———— ~~Atmos-0.1~~

..... ~~Atmos-0.3~~

0 : Incidence Angle  
HH Polarization

DATA AT C-BAND X Soybeans

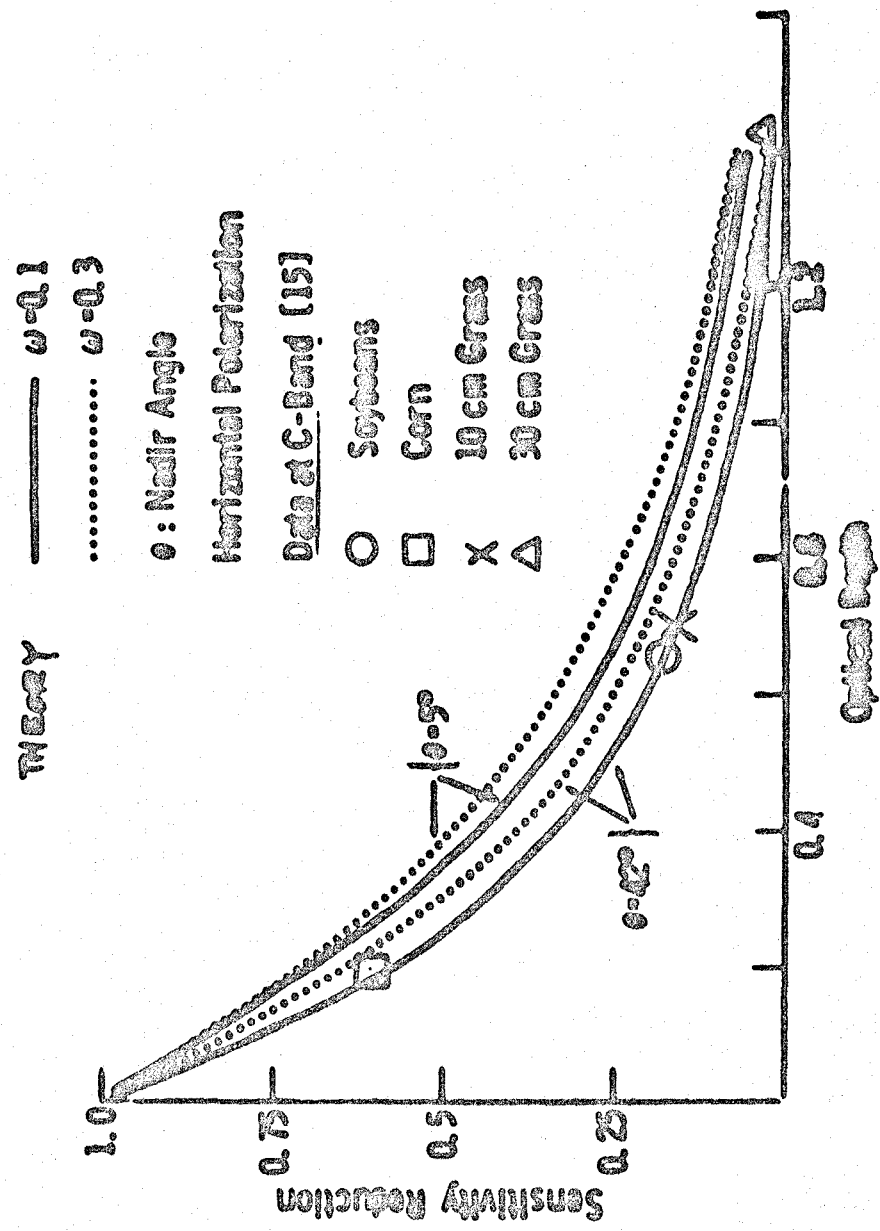
○ Wheat  
□ Corn



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# SENSITIVITY REDUCTION IN PASSIVE SENSING OF SOIL MOISTURE OVER VEGETATED AREA



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REMOTE SENSING OF EARTH TERRAIN

W. H.  
J. Kong  
M.I.T.

Research Lab-  
for Electronic,

BROAD GOALS AND INVESTIGATION OBJECTIVES

- \* Development of theoretical models for remote sensing of Earth terrain
- \* Data analysis and interpretation using the models developed
- \* Scene simulation
- \* Development of new remote sensing approaches and techniques

FIRST YEAR OBJECTIVES

- \* Development of numerous theoretical models that are applicable to the active and passive remote sensing of
  - plowed fields
  - atmospheric precipitation
  - vegetation
  - snow fields
- \* Data interpretation

## SECOND YEAR OBJECTIVES

- \* Continue development of theoretical models
  - Multi-layered model to investigate the effect of ice layers in the snowfields
  - Study scattering of waves from a layer of densely distributed dielectrical scatterers on top of homogeneous halfspace using the quantum mechanical potential approach
- \* Document all the computer programs for the theoretical models developed
- \* Start image simulation studies

## TECHNICAL PROGRESS AND ACCOMPLISHMENTS

Under the support of the fundamental research program, we have completed eight journal articles, six conference articles, and one technical report. In summary, we have: (1) solved the problem of microwave scattering from periodic surfaces using a rigorous modal technique; (2) studied scattering of electromagnetic waves from a randomly perturbed quasi-periodic surface with Kirchhoff approximation; (3) studied the combined random rough surface and volume scattering effects; (4) investigated the anisotropic effects of vegetation structures; (5) studied passive and active remote sensing of atmospheric precipitation with the vector radiative transfer equations; (6) studied the scattering of a plane wave obliquely incident on a half space of densely distributed spherical dielectric scatterers with quantum mechanical potential approach; and (7) applied the strong fluctuation theory to the study of electromagnetic wave scattering from a layer of random discrete scatterers.

The problem of microwave scattering from periodic surfaces is solved by using a rigorous modal technique which conserves energy, obeys reciprocity, and takes into account the multiple scattering and shadowing effects. The theoretical results have been applied to the calculation of the radar backscattering cross sections in active remote sensing and the brightness temperatures in passive remote sensing, and used to match field data from soil moisture measurements. The angular behavior of the brightness temperatures has been explained with the threshold phenomenon by considering the appearance and disappearance of the various Floquet modes.

The Kirchhoff approximation is used to study the scattering of electromagnetic waves from a randomly perturbed quasi-periodic surface. In order to more realistically model the plowed fields the rough surface is characterized as a composite surface with a Gaussian random variation, a sinusoidal variation and a narrow-band Gaussian random variation around the same spatial frequency. In the plowed fields there are some random variations on the period and amplitude of the sinusoidal variation as we move from one row to the next. This variation can be modelled by introducing the narrow-band Gaussian random process on top of the basic sinusoidal variations, which will cause the surface to be quasi-periodic. The scattering coefficients can be interpreted as a convolution of the scattering patterns for the sinusoidal and the random rough surfaces. For the backscattering cross sections we observe the occurrence of peaks whose relative magnitudes and the locations are explained in terms of the scattering patterns for sinusoidal surfaces.

The combined random rough surface and volume scattering effects have been studied by employing a Gaussian random surface and applying the small perturbation methods which is modified with the use of cumulant techniques. The rough surface effects are incorporated into the radiative transfer equations by modifying the boundary conditions for the intensities. The radiative transfer equations are then solved numerically using the Gaussian quadrature method and the results are illustrated and compared with experimental data.

The anisotropic effects of vegetation structures are investigated and the theoretical results are used to match experimental data. The azimuthally anisotropic behavior of the measurement result is attributed to the orientations of the vegetation stalks which were laid on the ground during the

field measurements. The effect of the soil moisture on the brightness temperature measurements from the wet and dry corn stalks has been clearly identified.

Both passive and active remote sensing of atmospheric precipitation are studied with the vector radiative transfer equations by making use of the Mie scattering phase functions and incorporating the rain drop size distributions. For passive remote sensing we employ the Gaussian quadrature method to solve for the brightness temperatures, and for active remote sensing an iterative approach carrying out to second order in albedo is used to calculate for the bistatic scattering coefficients and the backscattering cross sections per unit volume.

The scattering of a plane wave obliquely incident on a half space of densely distributed spherical dielectric scatterers is studied with quantum mechanical potential approach. The quasi-crystalline approximation is applied to truncate the hierarchy of multiple scattering equations and Percus-Yevick result is used to represent the pair distribution function. While results at high frequencies are calculated numerically, closed form solution are obtained in the low frequency limit for the effective propagation constants, the coherent reflected wave and the bistatic scattering coefficients.

The strong fluctuation theory is applied to the study of electromagnetic wave scattering from a layer of random discrete scatterers. The singularity of the dyadic Green's function is taken into account in the calculation of the effective permittivity functions. The correlation functions for the random medium with different scatterer constituents and size distributions are derived. Applying the dyadic Green's function for a two layer medium and using the bilocal and distorted Born approximations, the first and the second moments of the fields are calculated.

## **LIST OF PERSONNEL**

### **Academic and Research Staff**

Professor J. A. Kong:      Principal Investigator

Dr. L. Tsang

Dr. S. L. Chuang

### **Graduate Students**

Y. Q. Jin

S. Lin

J. K. Lee

R. T. Shin

## PUBLICATIONS

### A. Journal Articles

1. S. L. Chuang and J. A. Kong, "Wave scattering and guidance by dielectric waveguides with periodic surface," Journal of the Optical Society of America, vol. 73, no. 5, 669-679, May 1983.
2. Y. Q. Jin and J. A. Kong, "Passive and active remote sensing of atmospheric precipitation," Applied Optics, vol. 22, 2535-2545, Sept. 1983.
3. L. Tsang and J. A. Kong, "Scattering of electromagnetic waves from a half space of densely distributed dielectric scatterers," Radio Science, vol. 18, no. 6, 1260-1272, Nov.-Dec. 1983.
4. J. A. Kong, S. Lin, and S. L. Chuang, "Thermal microwave emission of periodic surface," IEEE Transactions on Geoscience and Remote Sensing, to be published.
5. R. T. Shin and J. A. Kong, "Scattering of electromagnetic waves from a randomly perturbed quasi-periodic surface," Journal of Applied Physics, to be published.
6. J. K. Lee and J. A. Kong, "Dyadic Green's functions for layered anisotropic medium," Electromagnetics, to be published.
7. L. Tsang, J. A. Kong, and R. T. Shin, "Radiative transfer theory for active remote sensing of a layer of nonspherical particles," Radio Science, to be published.
8. Y. Q. Jin and J. A. Kong, "Strong fluctuation theory for electromagnetic wave scattering by a layer of random discrete scatterers," Journal of Applied Physics, to be published.

### B. Conference Articles

9. J. A. Kong, "Theoretical models for microwave remote sensing of vegetation and soil moisture," AgRISTARS Symposium, Houston, Texas, December 1-2, 1982.
10. J. A. Kong, S. L. Lin, S. L. Chuang, and R. T. Shin, "Remote sensing of soil moisture and vegetation," URSI Symposium, Boulder, Colorado, January 5-7, 1983.



11. R. T. Shin and J. A. Kong, "Thermal microwave emission from a scattering medium with rough surfaces," URSI Symposium, Boulder, Colorado, January 5-7, 1983.
12. Y. Q. Jin and J. A. Kong, "Mie scattering of electromagnetic waves by precipitation," Optical Society of America Topical Meeting on Optical Techniques for Remote Probing of the Atmosphere, Lake Tahoe, Nevada, January 10-12, 1983.
13. L. Tsang and J. A. Kong, "Scattering of electromagnetic waves from a half-space of densely distributed dielectric scatterers," IEEE/APS Symposium and URSI Meeting, Houston, Texas, May 23-26, 1983.
14. L. Tsang and J. A. Kong, "Theory of microwave remote sensing of dense medium," IEEE/GRS Symposium and URSI Meeting, San Francisco, September 1983.

#### C. Technical Reports

15. R. T. Shin and J. A. Kong, "Emissivity of a two-layer random medium with anisotropic correlation function," Technical Report No. EWT-RS-41-8303, MIT, 1983.

## KEY VISUAL AIDS

### Figure Captions

- Figure 1 Geometrical configuration of the problem for wave scattering from sinusoidal surfaces.
- Figure 2 Brightness temperatures as a function of viewing angle for both the vertical and horizontal polarizations as compared with experimental data. Radiometer observation plane is parallel to the row direction.
- Figure 3 Brightness temperatures as a function of viewing angle for both the vertical and horizontal polarizations as compared with experimental data. Radiometer observation plane is perpendicular to the row direction.
- Figure 4 Brightness temperatures as a function of viewing angle for both the vertical and horizontal polarizations as compared with experimental data. Radiometer observation plane is not parallel to the row direction.
- Figure 5 Geometrical configuration of the problem for wave scattering from two-layer random discrete scatterers.
- Figure 6 Brightness temperature versus rain rate at 19.35 GHz.
- Figure 7 Horizontally polarized backscattering cross sections versus frequency for dry snow. Ice radius = 0.7 mm, fractional volume = 0.25.
- Figure 8 Horizontally polarized backscattering cross sections versus frequency for wet snow. Water drop radius = 0.4 mm, fractional volume = 0.02, ice radius = 0.7 mm, fractional volume = 0.23.
- Figure 9 Horizontally polarized backscattering cross sections versus snow wetness. Water drop radius = 0.4 mm, ice radius = 0.7 mm, total particle fractional volume = 0.2.
- Figure 10 Backscattering cross sections versus frequency for snowpack.
- Figure 11 Depolarized backscattering cross sections versus frequency for snowpack.

Figure 12 Reflectivity versus snowfall rate at 9.375 GHz.

Figure 13 Reflectivity versus snowfall rate at 9.375 GHz.

Figure 14 Snowfall attenuation versus snow mass concentration at 95 GHz.

Figure 15 Snowfall attenuation versus snow mass concentration at 140 GHz.

Figure 16 Snowfall attenuation versus snow mass concentration at 217 GHz.

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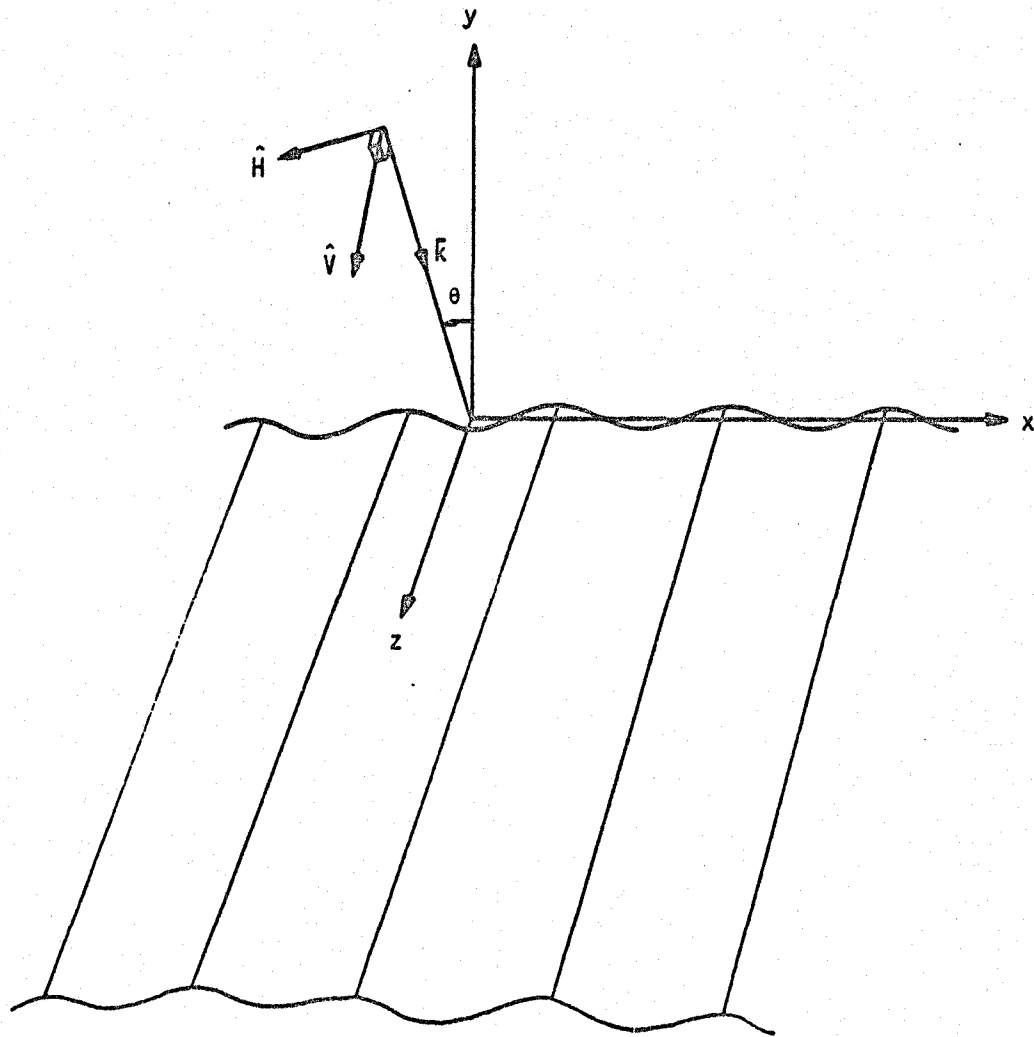


Figure 1

Figure 2

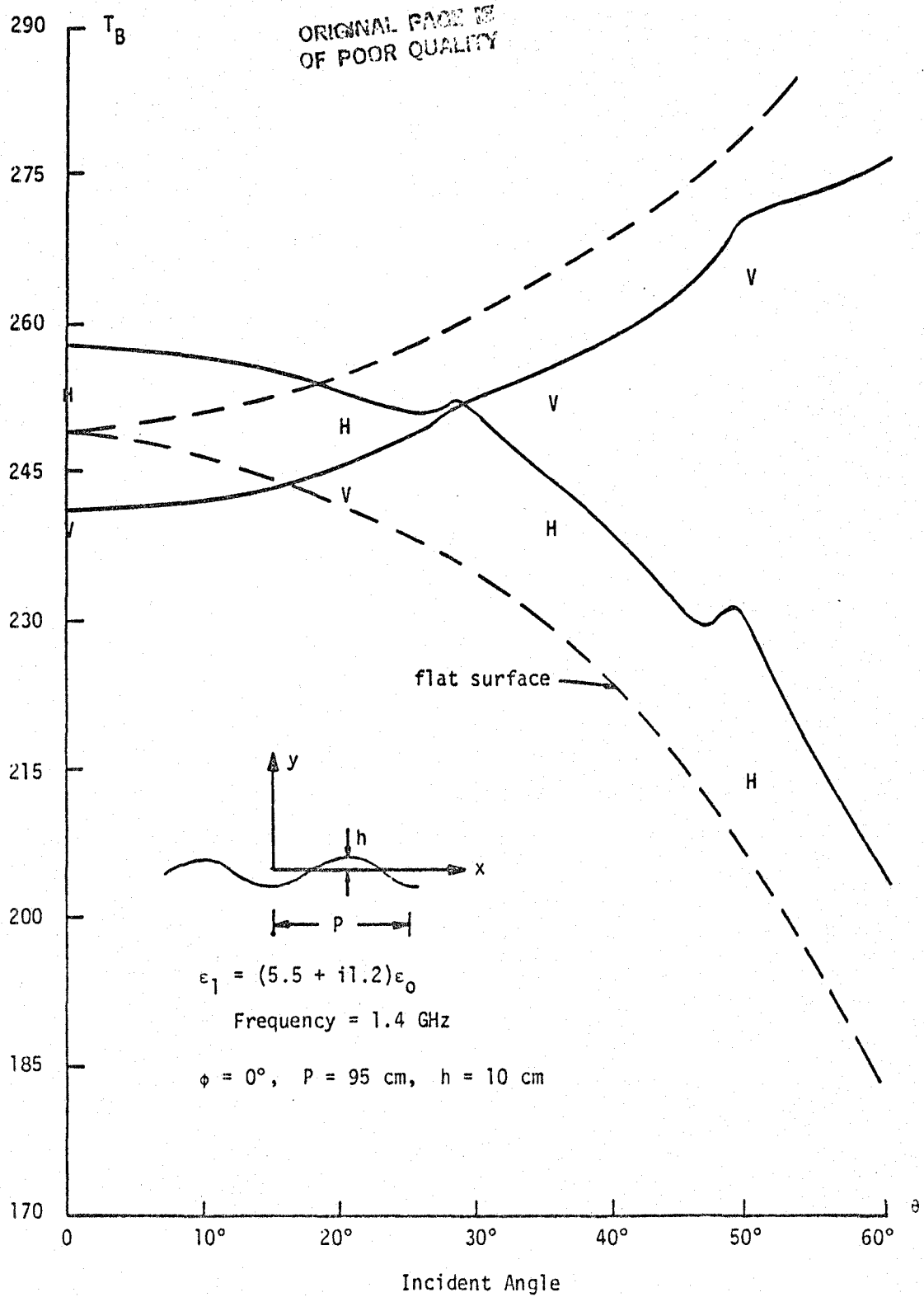


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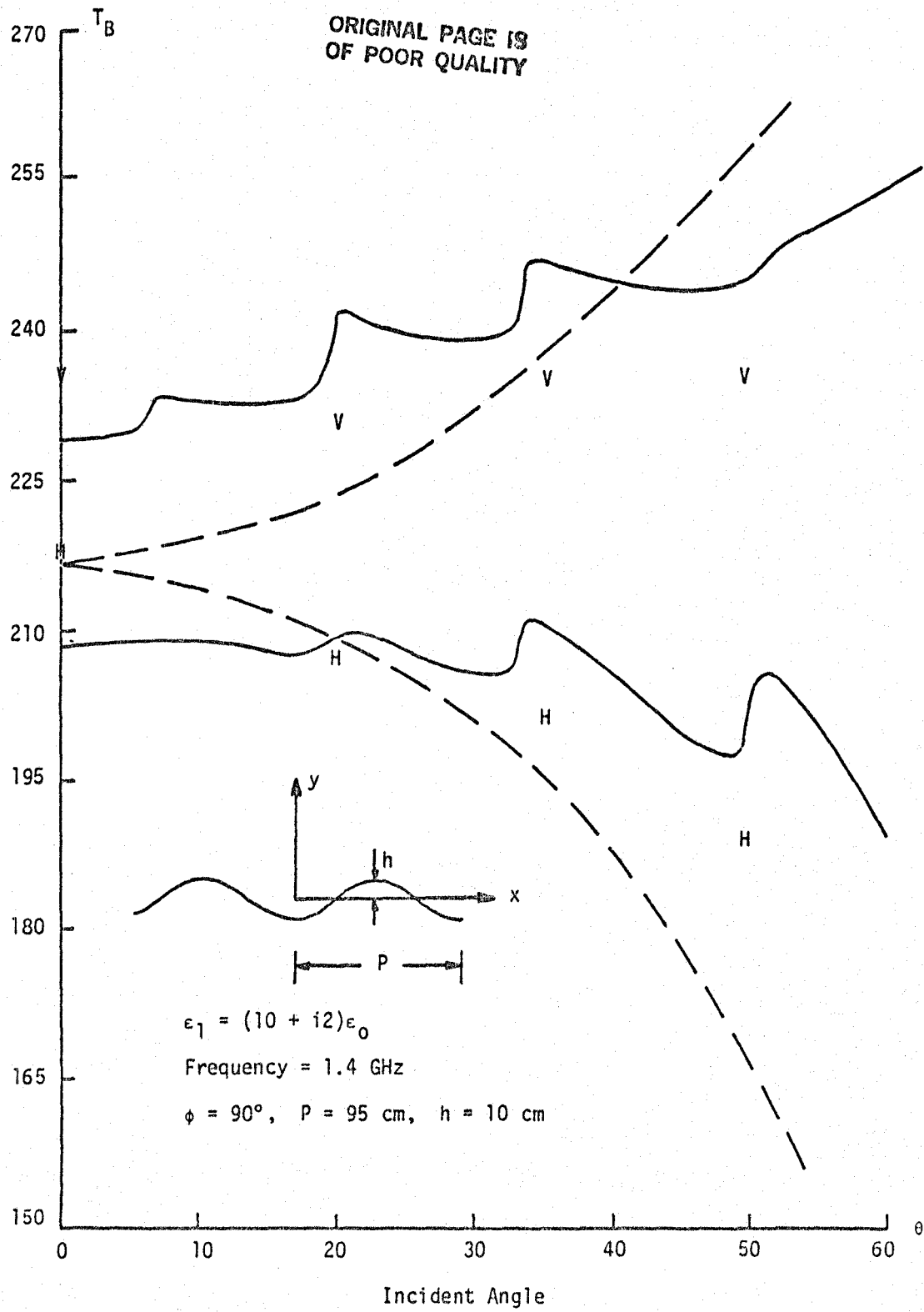
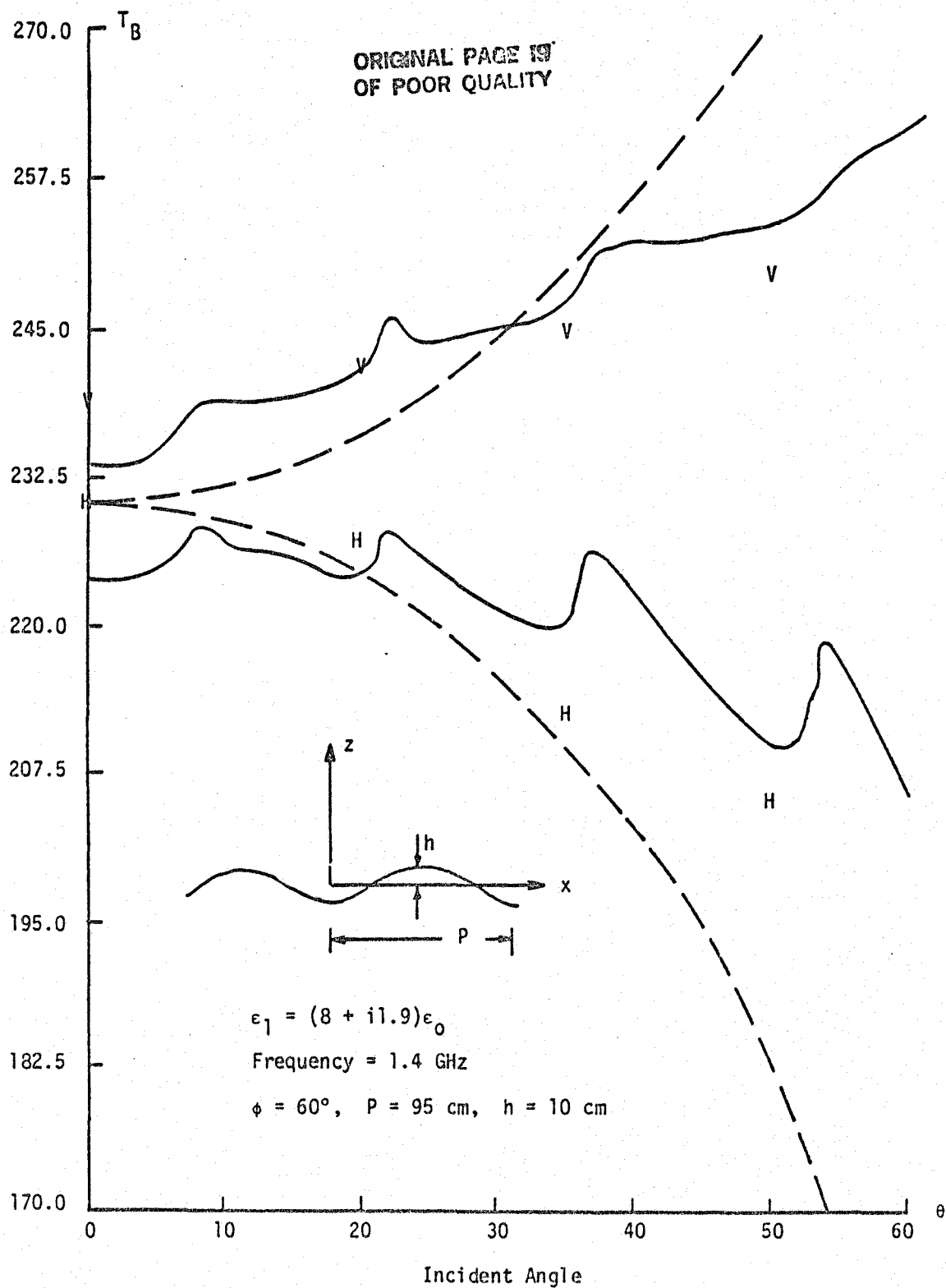


Figure 4



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Figure 5

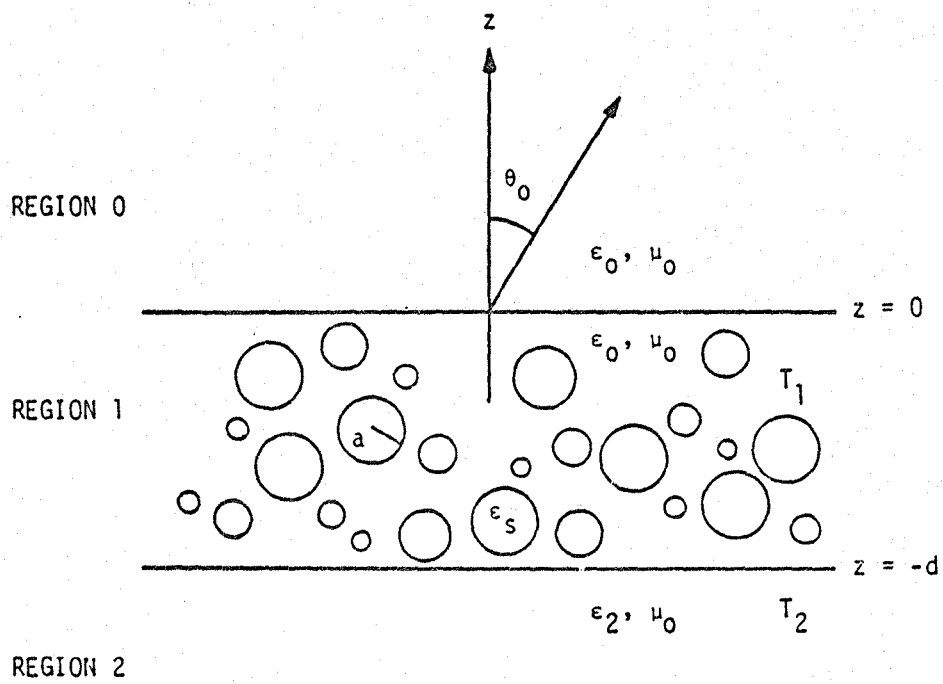
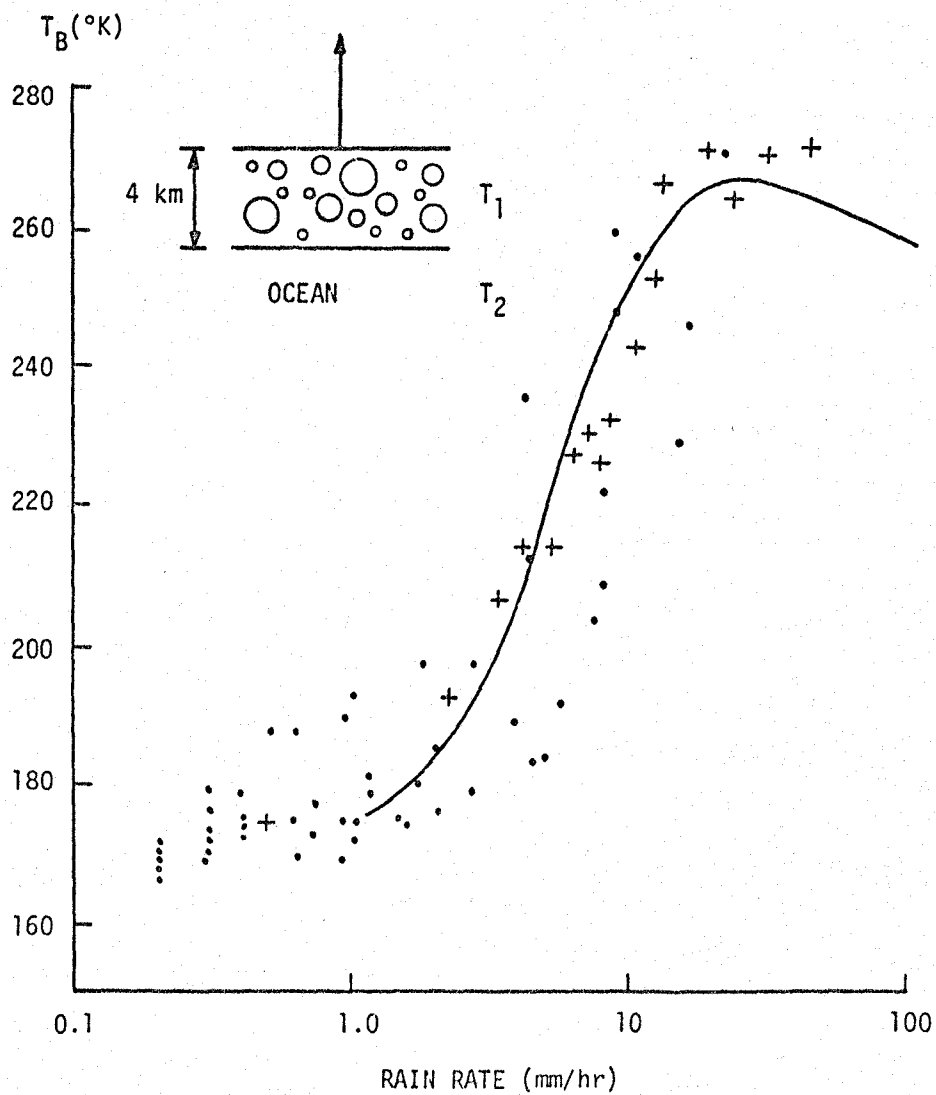




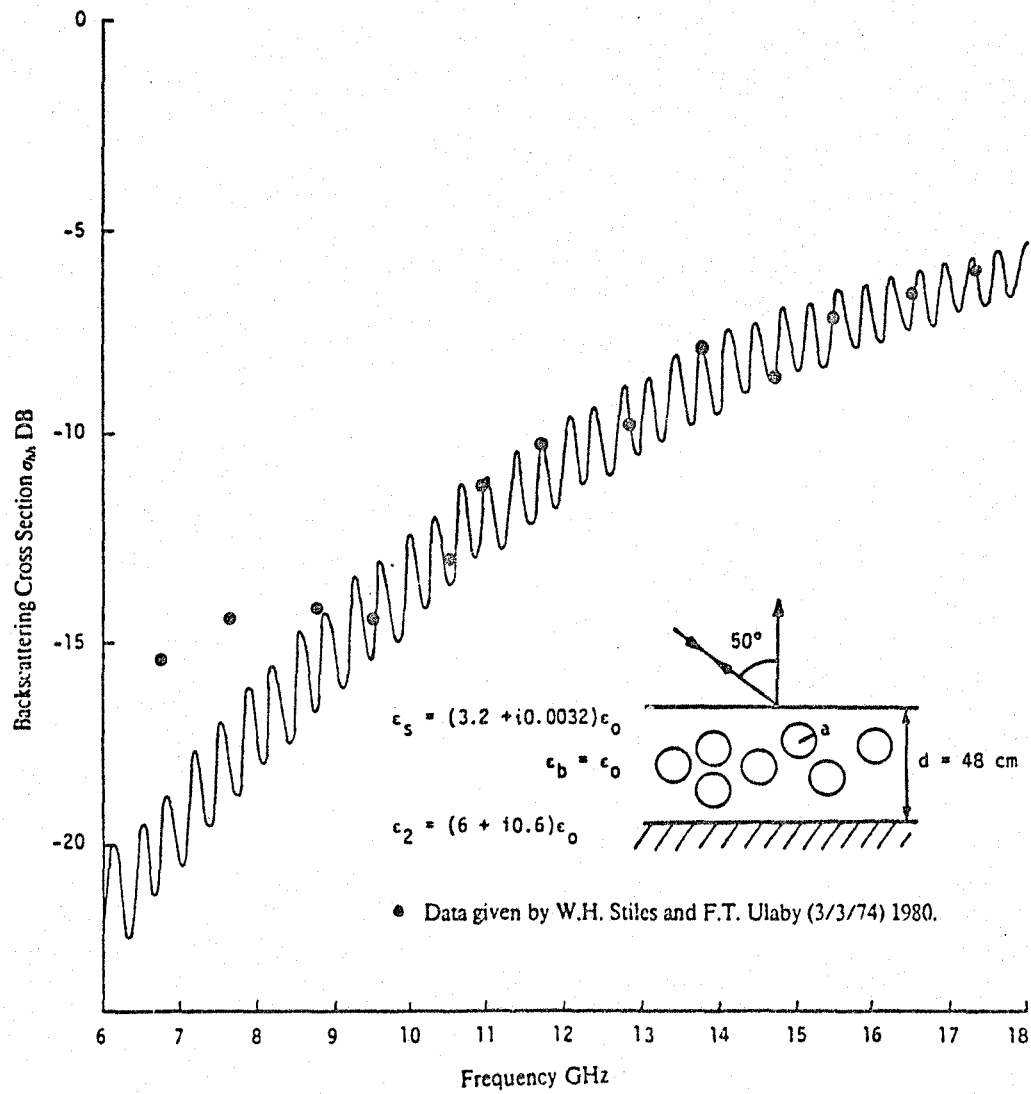
Figure 6

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Figure 7



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Figure 6

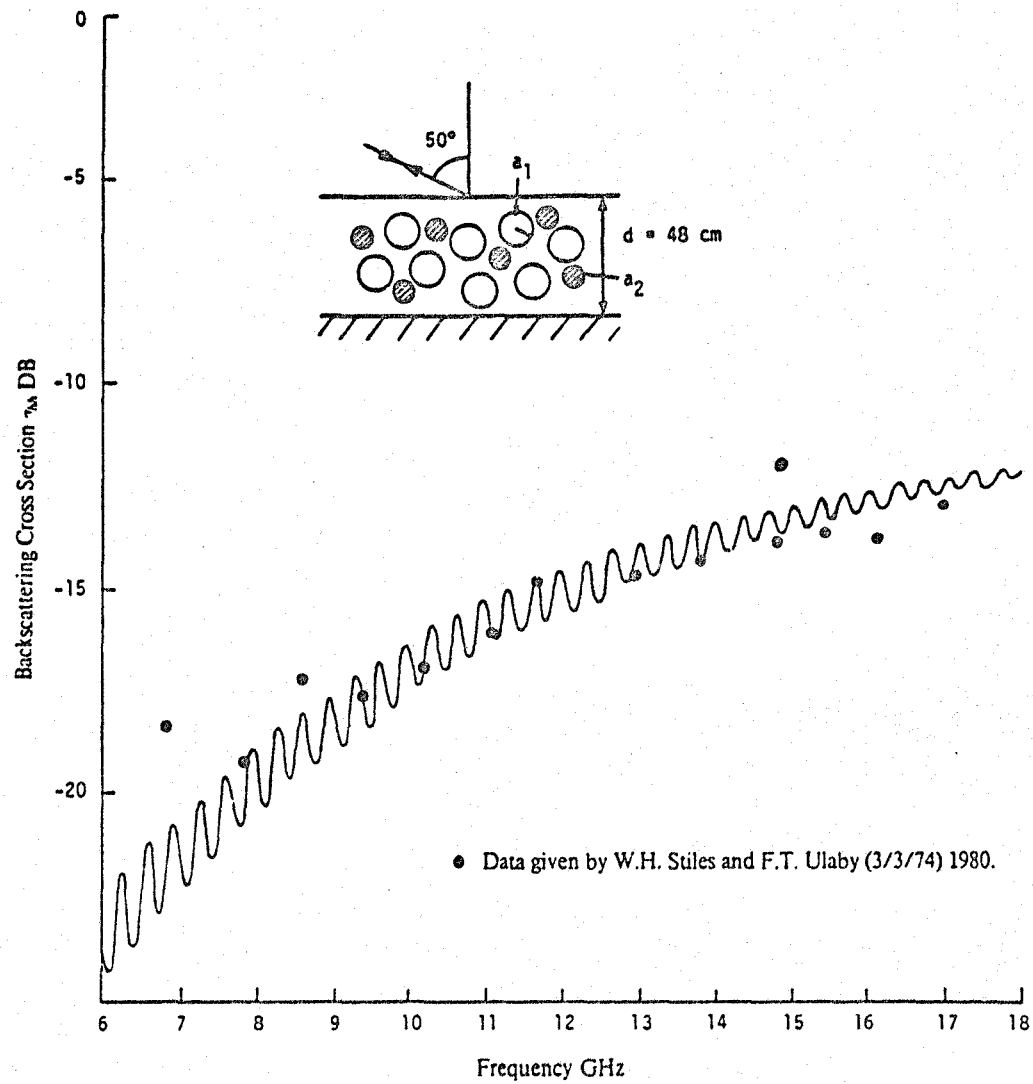
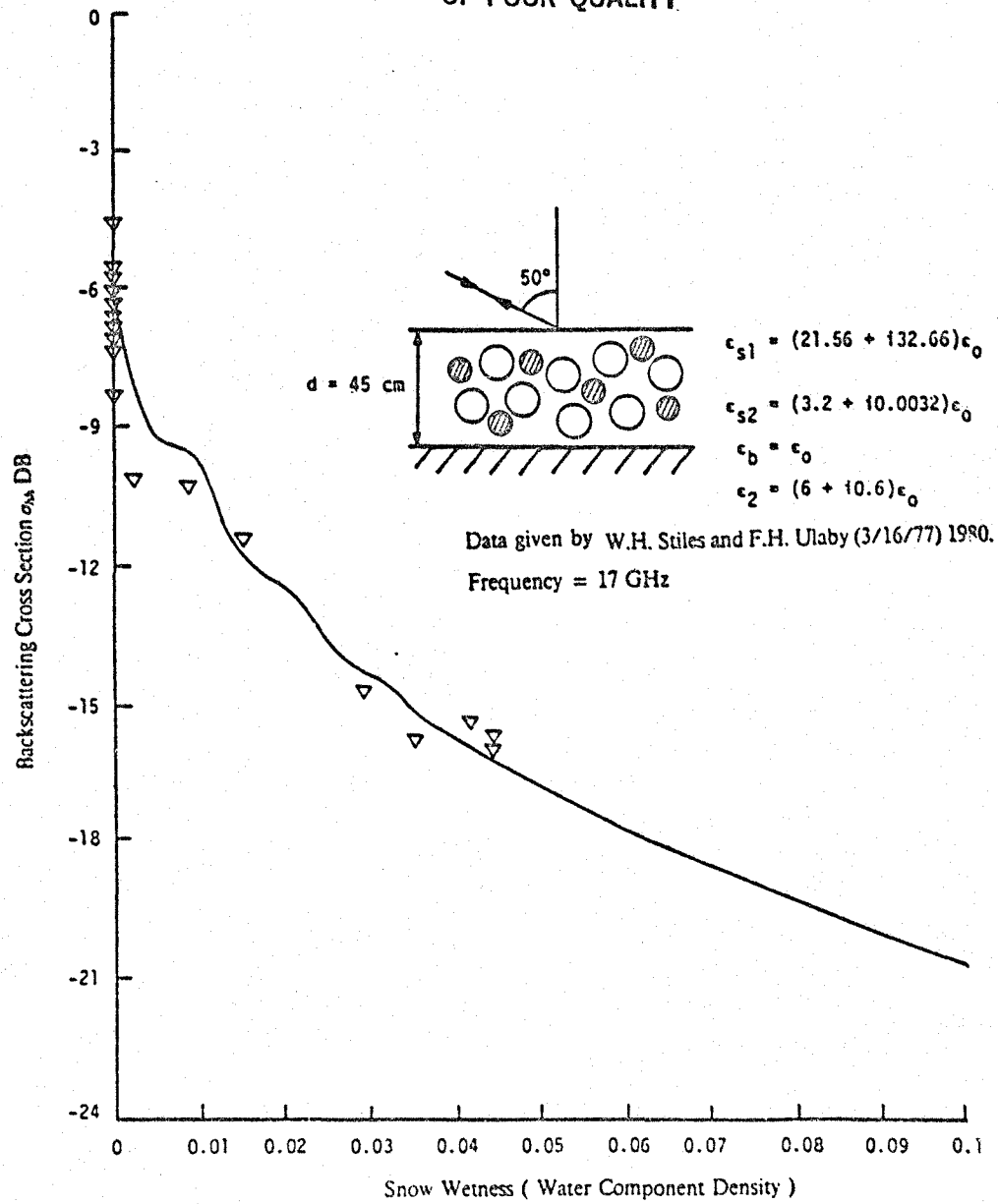


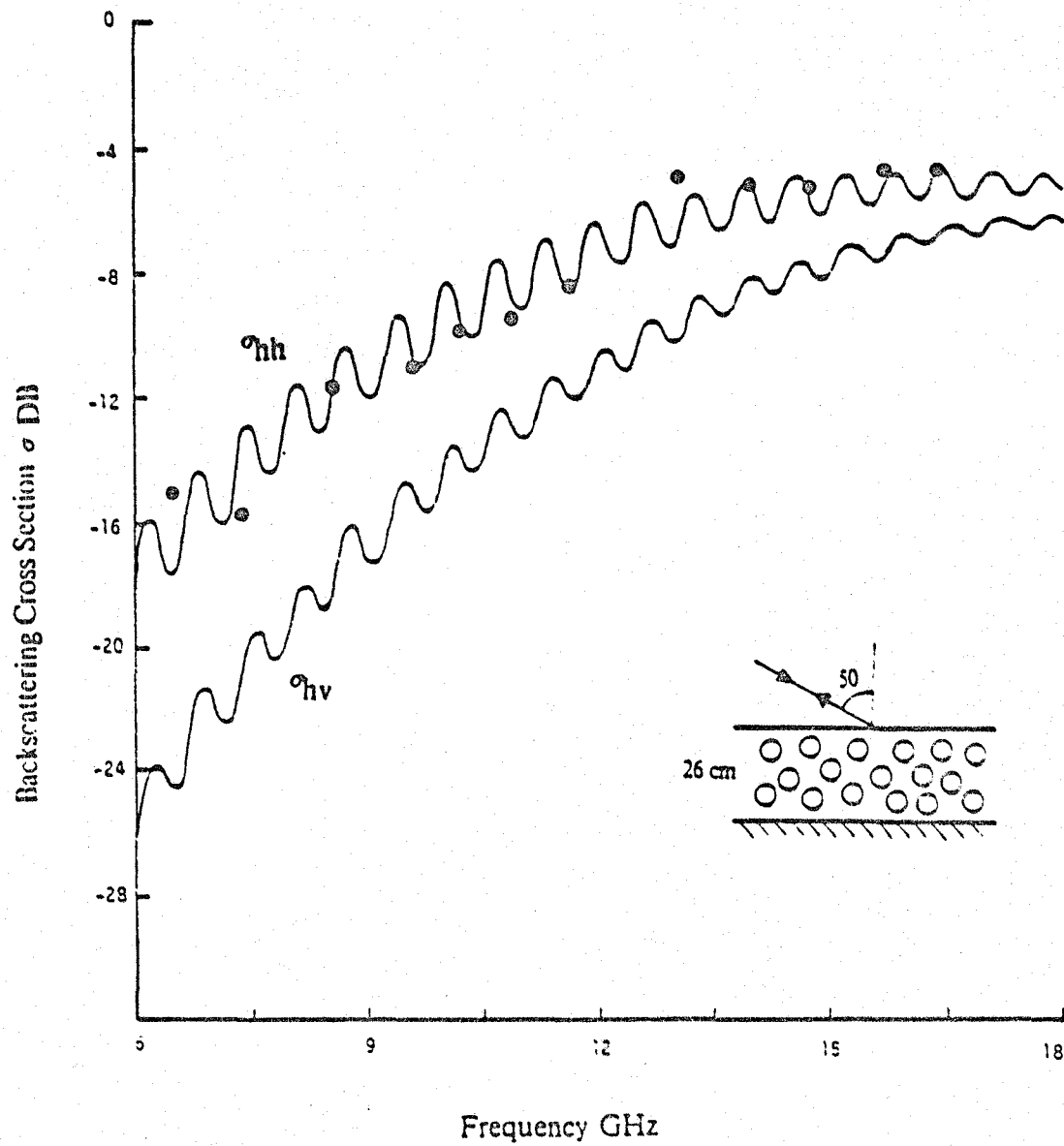
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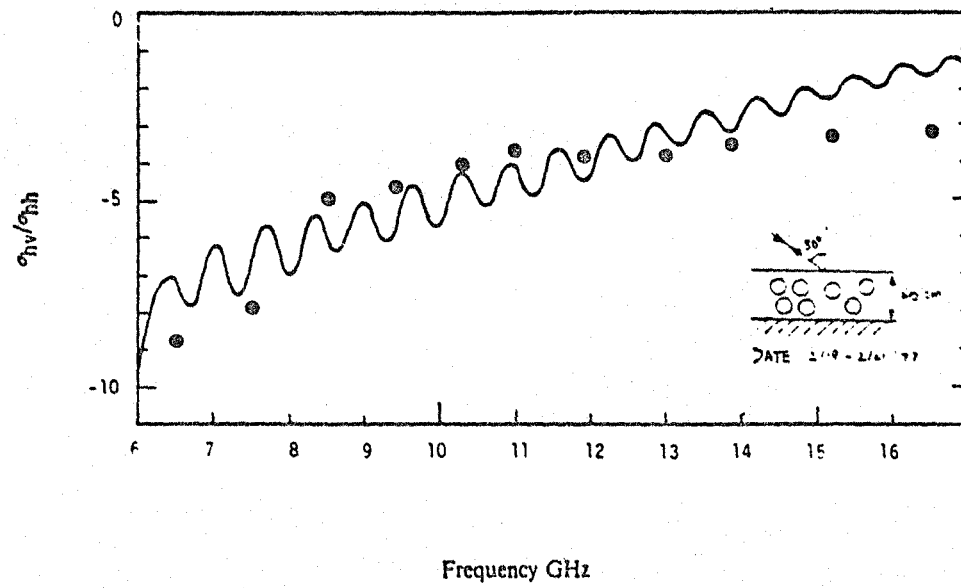
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Figure 10



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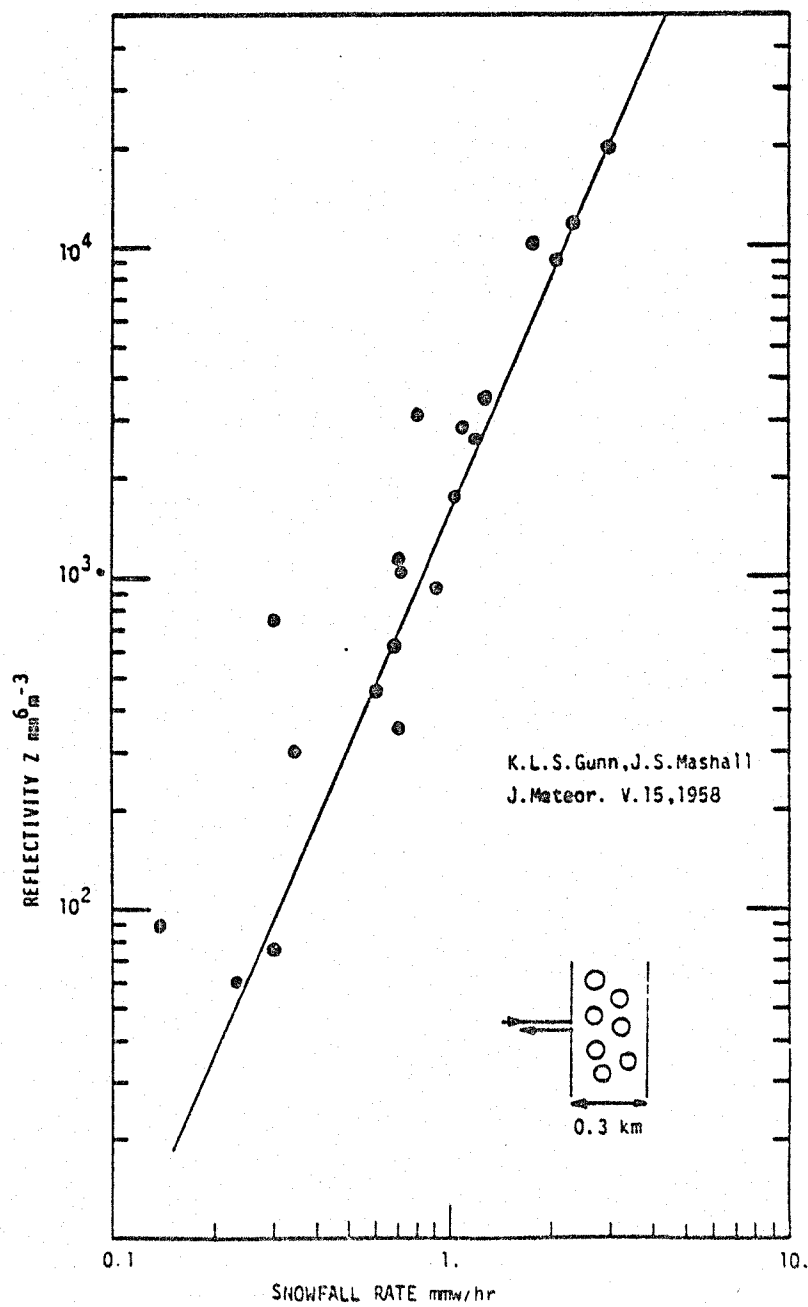
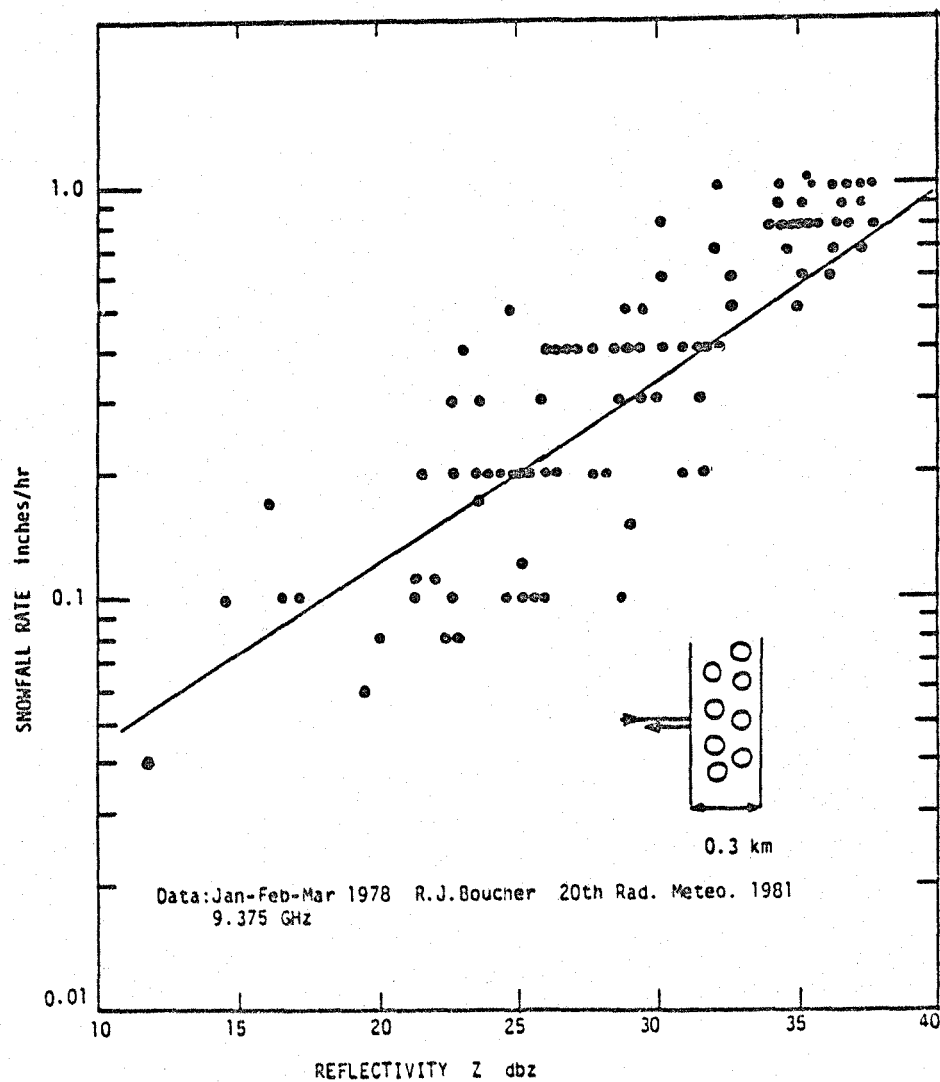


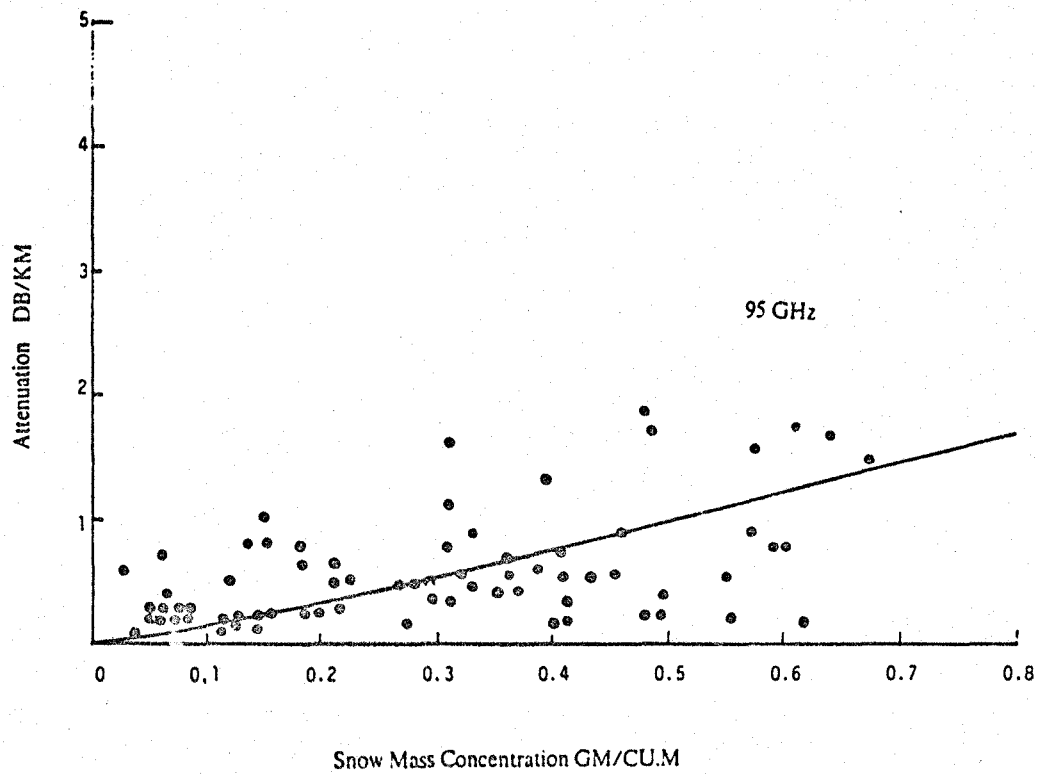
Figure 13





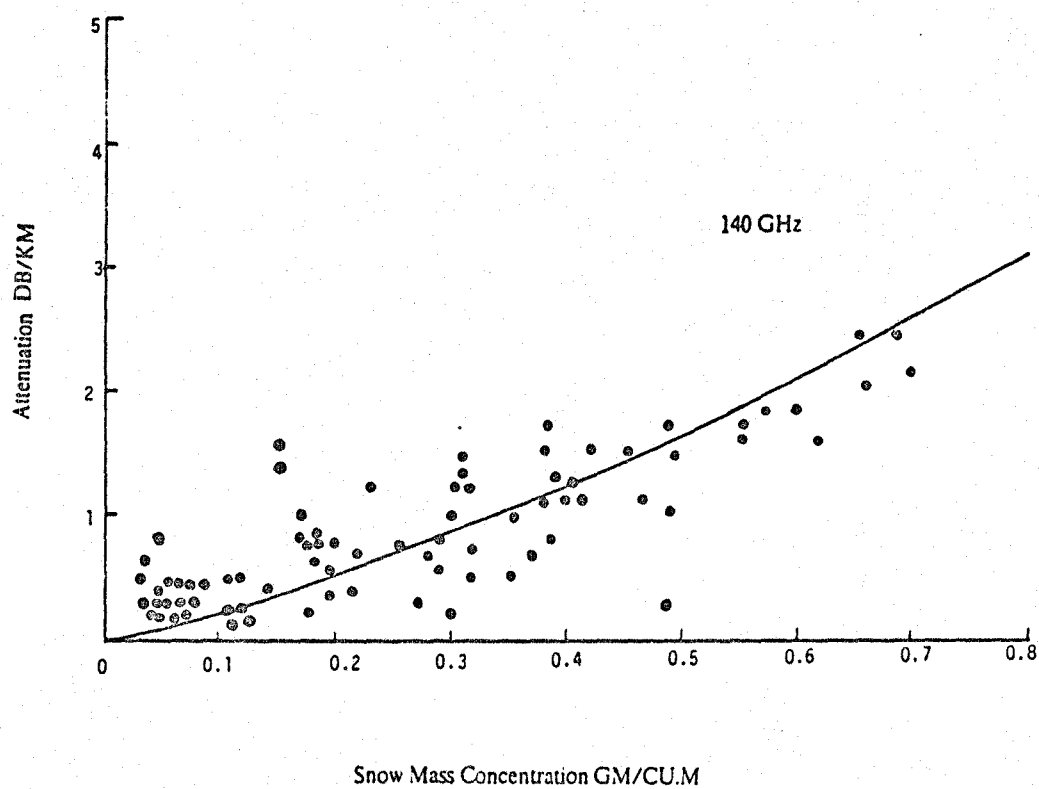
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Figure 14



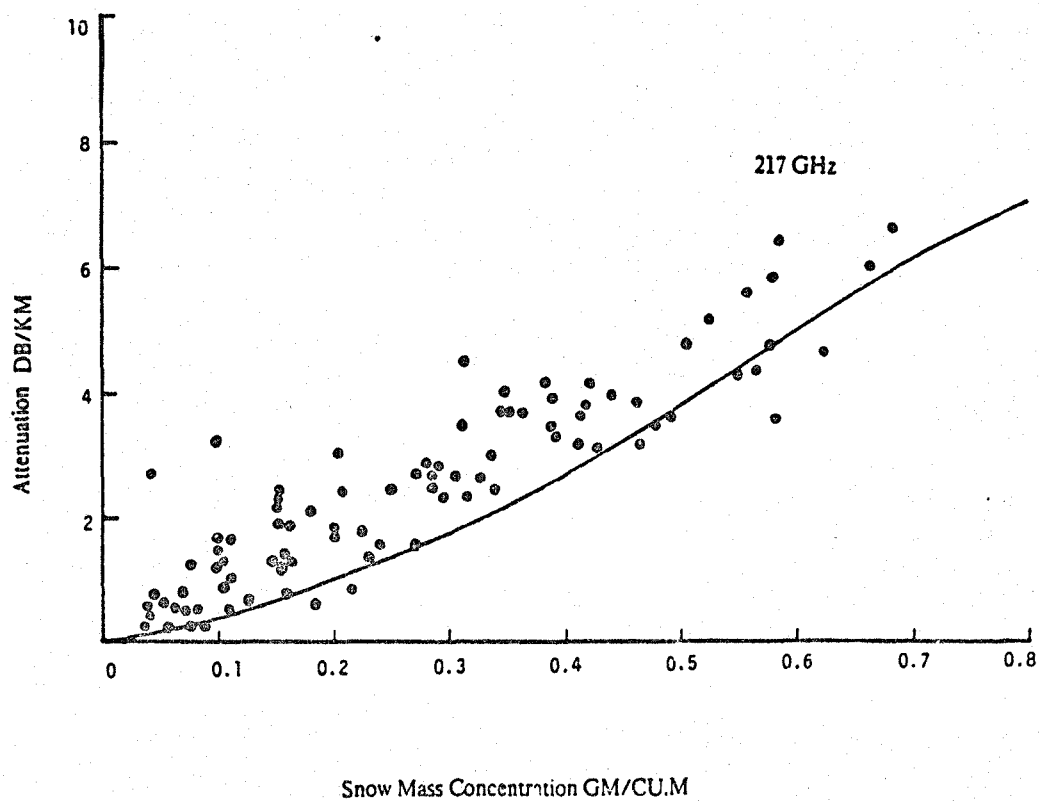
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Figure 15



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Figure 16



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DISCRETE RANDOM MEDIA TECHNIQUES FOR MICROWAVE MODELING  
OF VEGETATED TERRAIN

R. Lang  
Geo. Wash. Univ.

Dept of Electrical  
Engineering & Computer  
Science

A. BROAD GOALS AND INVESTIGATION OBJECTIVES

- Use discrete scatter theory to model vegetation (crops and forested regions) in microwave region.
- Develop models for scatterers and ground.
- Multiple scattering analysis-relate model parameters to average scattered power.
- Develop inversion techniques to remotely determine model parameters.

B. FIRST YEAR OBJECTIVES

- Develop models for discs, stems and trunks.
- Derive coherent and incoherent distorted Born approximation (DBA) for resonant scatterers.
- Account for rough ground surface.
- Model mature soybean crop.

C. TECHNICAL PROGRESS AND ACCOMPLISHMENTS

- Scattering models developed for electrically thin and thick discs, thin stems and infinite trunks.
- Backscattering coefficients computed by coherent and incoherent DBA for:
  - (i) slab geometry
  - (ii) thin discs and thin stems
  - (iii) Rician rough surface
- Backscattering coefficients decomposed naturally into direct, direct-reflected and reflected components.
- Theoretical and experimental results compared for mature soybean crop in lower GHz region.

#### D. RESULTS/SCIENTIFIC FINDING

- Coherent and incoherent DBA results are close for like polarizations-differ substantially for cross polarization.
- Theory used to model mature soybean crop in 1-4 GHz region. Findings are:
  - (i) For HH polarization- leaves more important than stems at all angles.
  - (ii) For VV polarization- stems more important than leaves at large angles of incident.
  - (iii) Rough surface effects are dominant at angles less than 15°.
  - (iv) Direct-reflected contributions more important than direct contributions for most ground moistures.
- Good agreement obtained between Ulbaly, et al, (IEEE-GE, 1979) soybean data and theory at 1.5 GHz.

#### E. SIGNIFICANCE TO GENERAL RESEARCH AREA

- Discrete scatter DBA method provides a good vegetation modeling technique in the lower microwave region (1-4GHz).
- Isolates dominant scatter types within the canopy.
- Can be used to develop crop classification techniques.
- Ground moisture can be related to backscattered power.

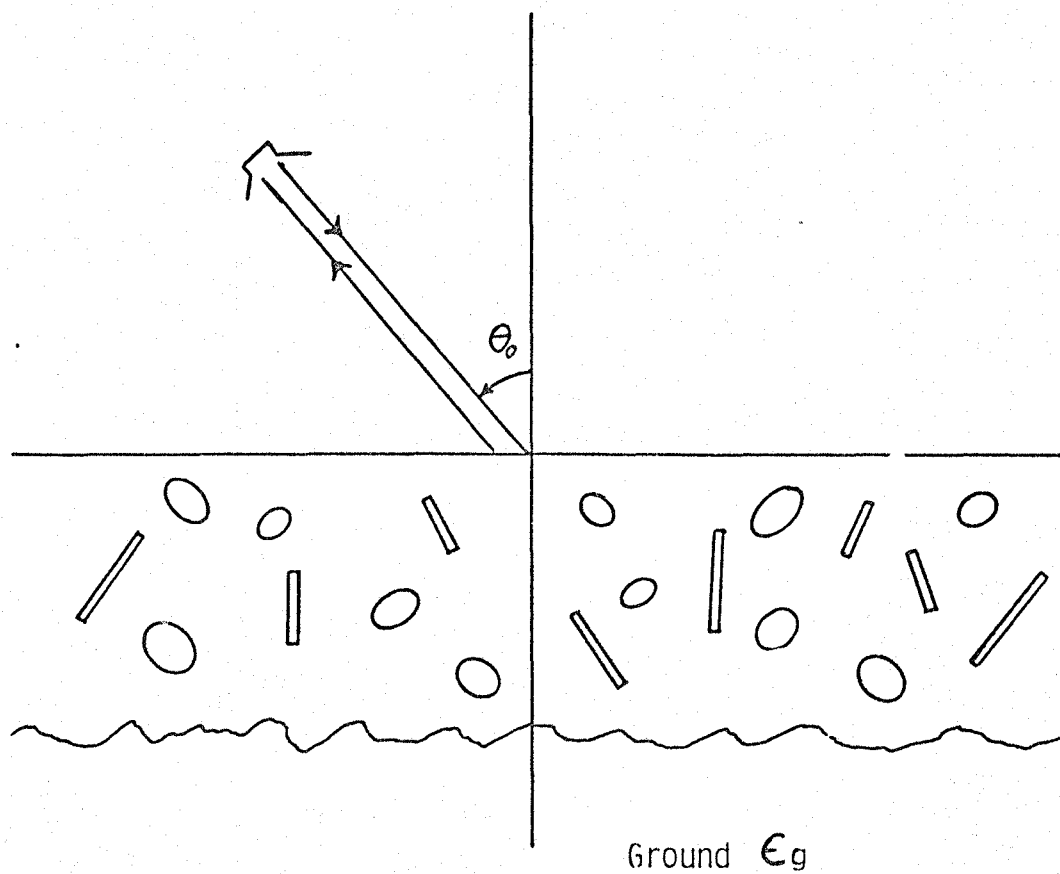
#### F. RELATIONSHIP TO OTHER FUNDAMENTAL RESEARCH SRAEC INVESTIGATIONS

- Kong- uses predominantly continuous random medium modeling.
  - lately emphasizing dense media (snow).
- Fung- Incoherent transport theory and rough surface modeling of snow, ice and vegetation.
- Gerstl- Incoherent transport theory with empirically determined phase functions.
- Other researchers- optical, infrared or microwave experimental.

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# MULTI-COMPONENT VEGETATION LAYER

OVER A ROUGH GROUND



# SCATTERED FIELD

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$$E_s = E_d + E_{dr1} + E_{dr2} + E_r + E_{sur}$$

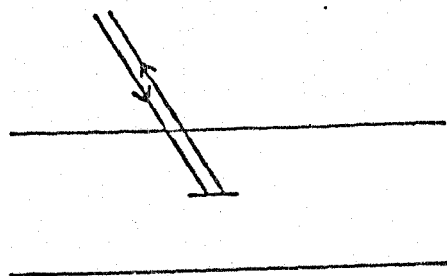
## BACKSCATTERING COEFFICIENTS

$$\sigma^{\circ} = \int_v E_s E_s^* dv$$

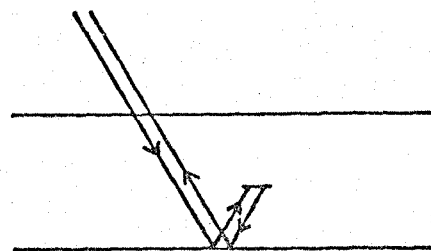
$$\sigma^{\circ} = \sigma_d^{\circ} + \sigma_{dr}^{\circ} + \sigma_r^{\circ} + \sigma_{sur}^{\circ}$$

WHERE

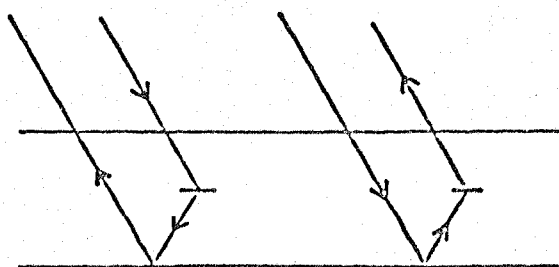
$$\sigma_{dr}^{\circ} = \sigma_{dr1}^{\circ} + \sigma_{dr2}^{\circ} + \sigma_{dr12}^{\circ}$$



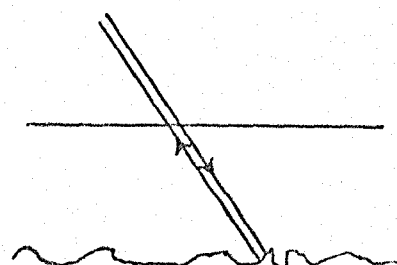
direct



reflected



direct-reflected



surface



MODEL PARAMETERS  
SOYBEANS (AUGUST)

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LEAVES

$$a_{1L} = 2.5\text{cm}$$

$$\rho_{1L} = 333/\text{m}^3$$

$$a_{2L} = 3.5\text{cm}$$

$$\rho_{2L} = 333/\text{m}^3$$

$$a_{3L} = 5.0\text{cm}$$

$$\rho_{3L} = 333/\text{m}^3$$

$$T = .2\text{mm}$$

$$V_m = .7$$

STEMS

$$L = 20\text{cm}$$

$$a_s = 1.3\text{mm}$$

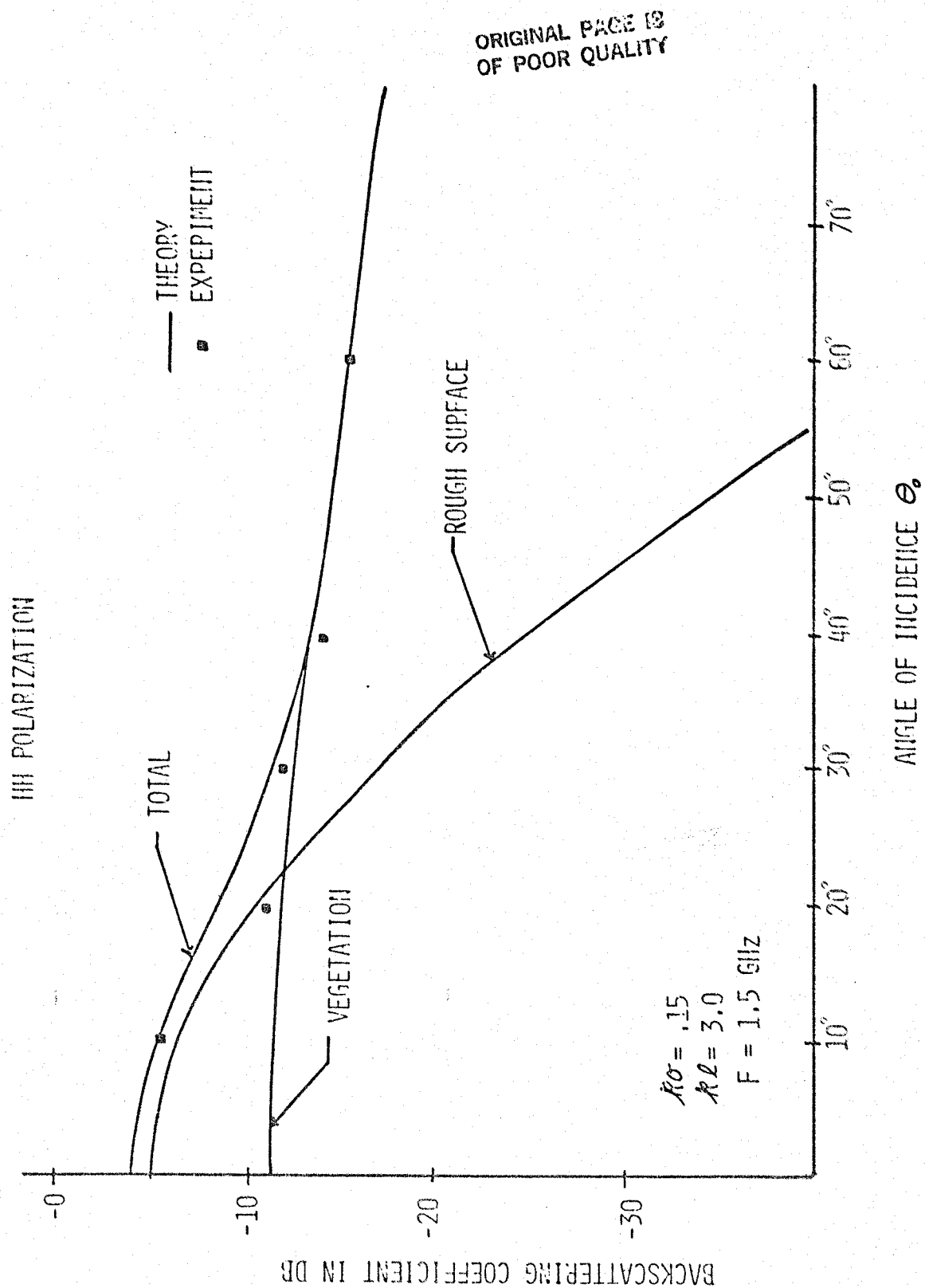
$$\rho_s = 1000/\text{m}^3$$

$$V_m = .7$$

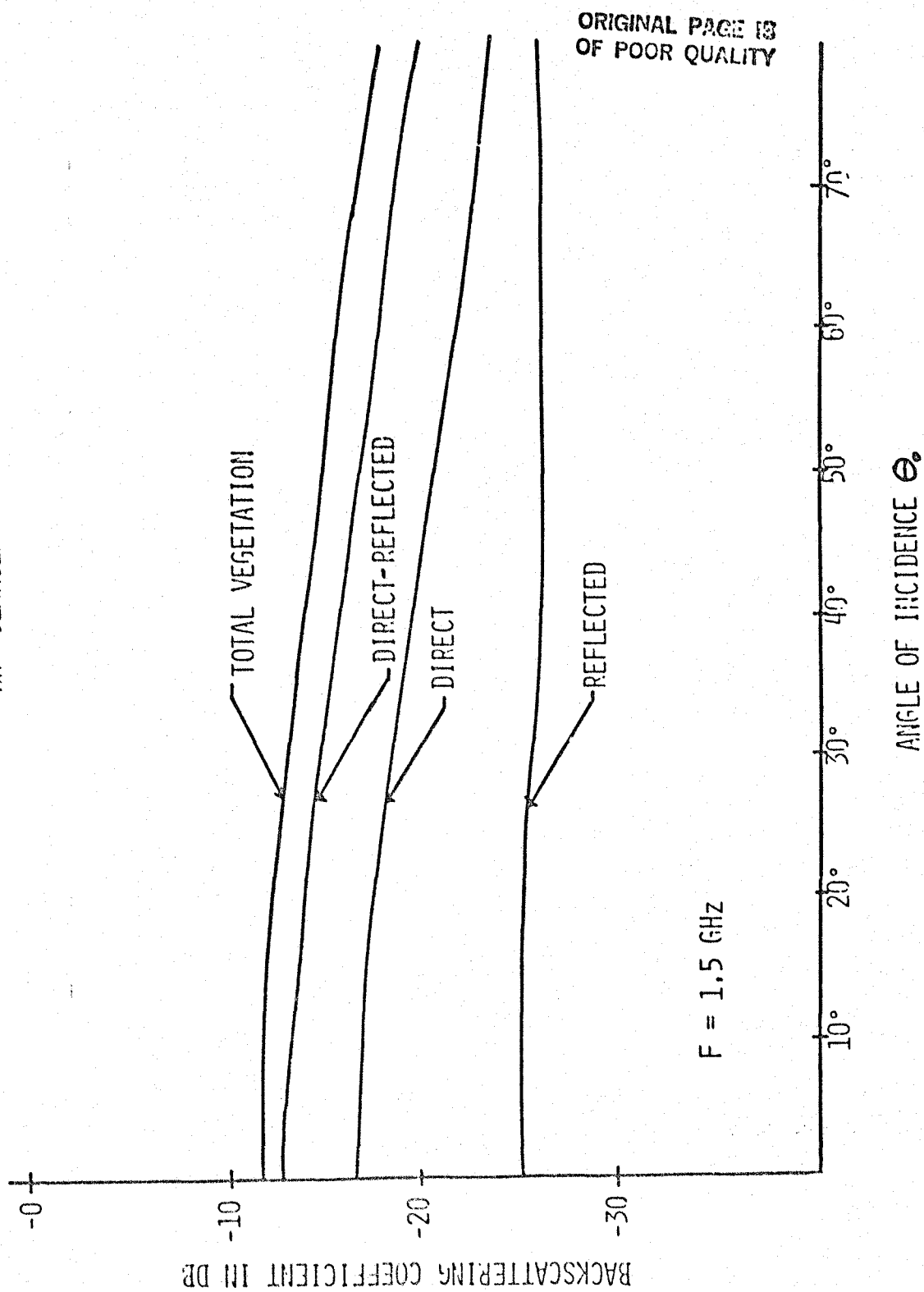
SLAB

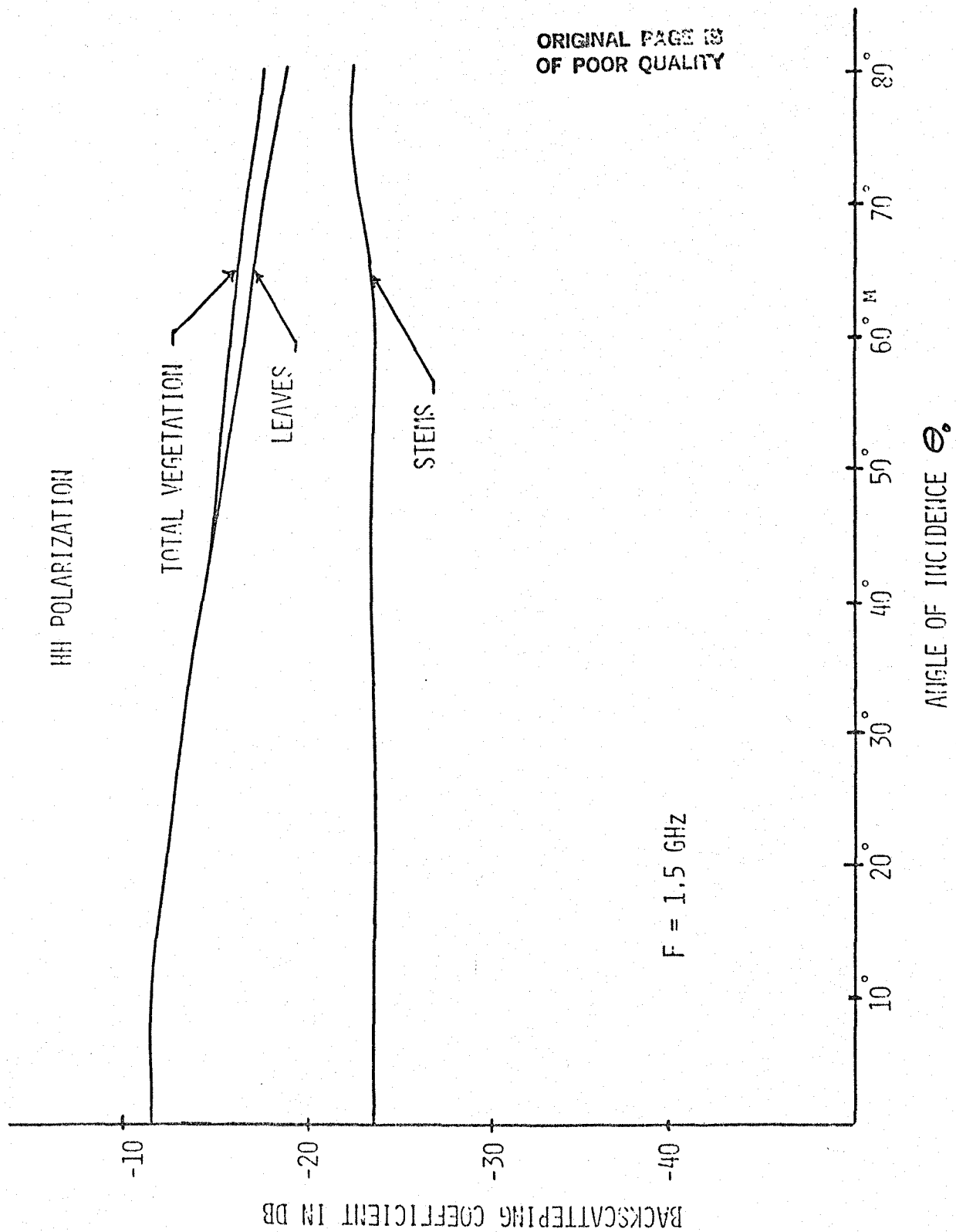
$$D = .6\text{m}$$

$$S.M. = .39\text{G}/\text{cm}^3$$



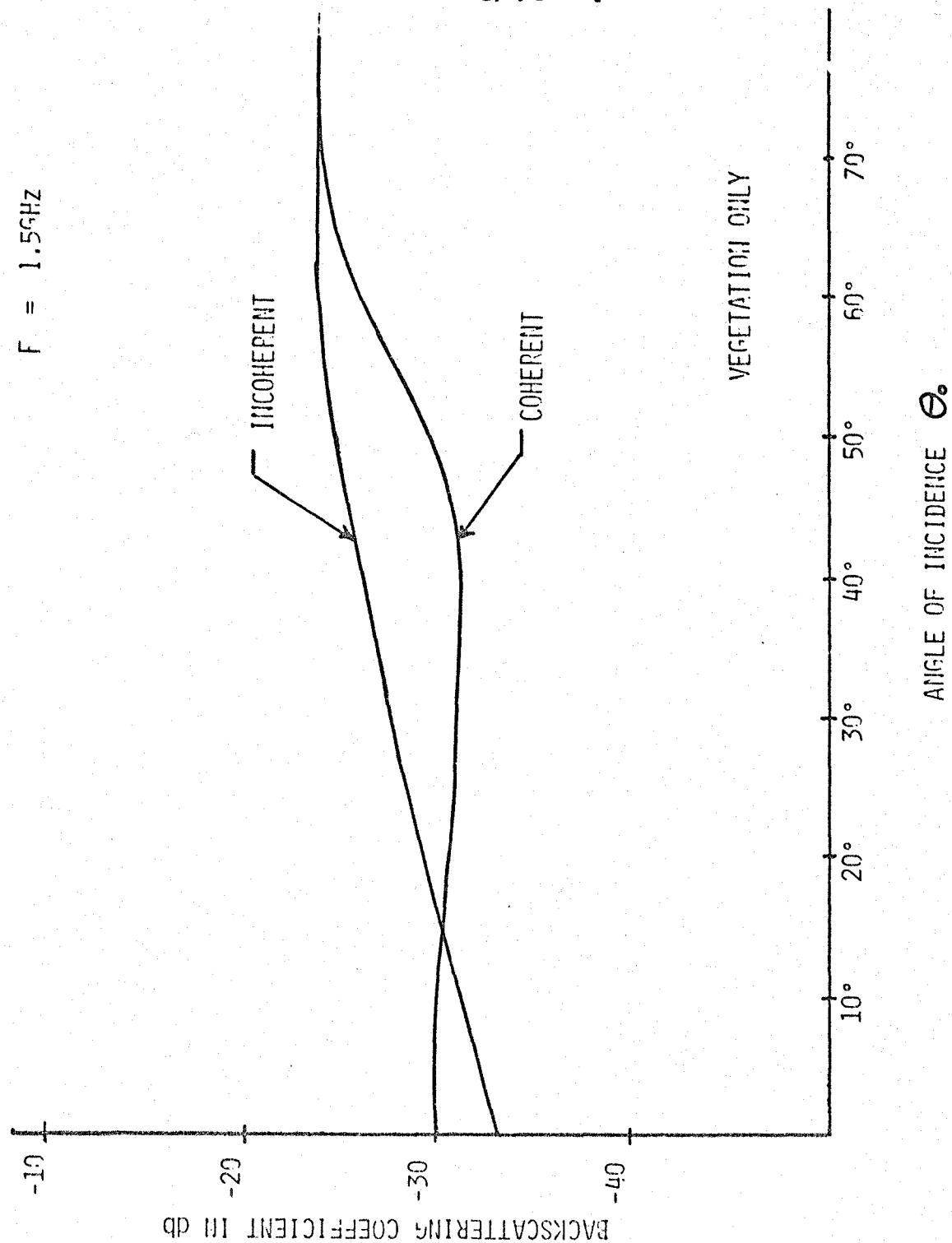
HH POLARIZATION





HV - POLARIZATION

$F = 1.5\text{GHz}$



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MEASURING AND MODELING OF THE DIELECTRIC PROPERTIES AND  
ATTENUATION OF VEGETATION

Ph.D.  
F. Ulaby  
U. of Kansas

INVESTIGATION SYNOPSIS

Remote  
Sensing  
Lab

(a) Investigation Objectives:

- (1) To measure the microwave dielectric properties of vegetation material as a function of moisture content and microwave frequency,
- (2) to develop dielectric mixing models for the vegetation-water mixture,
- (3) to develop a model for the loss factor of a vegetation canopy,
- (4) to relate the results of (1) and (2) to (3), and
- (5) to test the model in (3) against direct canopy transmission measurements.

(b) First-Year Objectives:

- (1) To build dielectric systems, develop measurement techniques for vegetation samples, and calibrate the system using materials of known dielectric properties,
- (2) to make a limited number of measurements of the dielectric properties of plant samples,
- (3) to demonstrate the feasibility of direct canopy transmission measurements, and
- (4) to examine dielectric mixing models.

(c) Technical Progress and Accomplishments

- (1) All first-year objectives have been realized.
- (2) Approximately 70 percent of the overall investigation objectives have been realized, and we expect to realize all stated objectives by the end of this two-year investigation.

(d) Results/Scientific Findings

(1) Microwave dielectric measurements of vegetation material

- Volume: The amount of data acquired in this project is at least an order of magnitude greater in volume than the total cumulative amount of data reported in the literature to date.

- Firsts: This is the first investigation to generate spectral measurements of the dielectric constant of vegetation material in the microwave region. Also, this is the first study to establish the importance of salinity (of the liquid contained in the vegetation material) as it relates to dielectric properties at frequencies below 4 GHz.

(2) Model for the Dielectric Constant of Vegetation Material

Several dielectric mixing models were examined in terms of the measured data; some of the models were rejected while others were extended. Although the number of potentially applicable models has been narrowed to two fundamentally different types, it was not possible to proceed further until additional experiments are conducted.

(3) Measurements of Canopy Loss Factor

Previous attempts (by Kansas University investigators as well as by investigators at other institutions) to measure the loss factor (inverse of transmissivity) of vegetation canopies at microwave frequencies have led to poor estimates, at best. A new technique was developed in this investigation which has proven to be both accurate and repeatable. The technique was used to measure the loss factor of soybeans and corn canopies over the full growing season and of wheat heads and stalks separately.

(e) Significance to General Research Area (e.g., Atmospheric Studies, Microwave, etc.) and (f) Relationship to Other Fundamental Research SRAEC Investigations

The results outlined above should prove very useful in the development of future models of the radar backscattering coefficient of vegetation canopies.

(g) Second-Year Objectives

See (a). (This is a two-year project).



(h) Study Participants and Affiliations

F. Ulaby, Principal Investigator

C. Martin, Co-Investigator, Asst. Prof. of Botany

R. Jedlicka, Graduate Student pursuing a Ph.D. degree

C. Allen, Graduate Student pursuing a Ph.D. degree

M. El-Rayes, Graduate Student pursuing a Ph.D. degree

M. McKinley, Graduate Student pursuing an M.S. degree

(i) Publications

- (1) Ulaby, F. T., and R. P. Jedlicka, "Microwave Dielectric Properties of Plant Materials," accepted for publication in IEEE Transactions of Geoscience and Remote Sensing, 1984. (Attached)
- (2) Jedlicka, R. P., and F. T. Ulaby, "Measurements of the Microwave Dielectric and Attenuation Properties of Plants," National Radio Science Meeting (URSI Commission F), University of Colorado, Boulder, January 5-7, 1983. (Abstract attached)
- (3) Ulaby, F. T., R. P. Jedlicka, and C. T. Allen, "Measuring and Modeling the Dielectric and Attenuation Properties of Vegetation," to be presented at the International Union of Radio Science Meeting (URSI Commission F), Toulouse, France, January 16-20, 1984. (Abstract attached)
- (4) Allen, C. T., and F. T. Ulaby, "Modeling the Polarization Dependence of the Attenuation in Vegetation Canopies," to be presented at the 1984 International Geoscience and Remote Sensing Symposium (IGARSS '84), Strasbourg, France, August 27-30, 1984. (Abstract attached)
- (5) Ulaby, F. T., "Microwave Properties of Vegetation Canopies: An Overview," International Colloquium on Spectral Signatures of Objects in Remote Sensing, Bordeaux, France, September 13-16, 1983. (Attached)

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DETERMINATION OF THE SOURCES OF RADAR SCATTERING

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R.K Moore, K. Zoughi, L.K Wu, A. Afifi, F.T Ulaby  
U. of Kansas

OBJECTIVE: Determination of the backscatter sources in vegetation canopies and surface targets.

OBSERVATION: Suppose a Radar Scatterometer is used to measure the backscattering coefficient  $\sigma^0$  of a canopy.

FUNDAMENTAL QUESTIONS:

- 1) How much of the backscattered energy is due to:
  - a) Direct volume backscatter by the canopy?
  - b) Direct backscatter by the soil (including attenuation effect of the canopy) ?
  - c) Indirect backscatter by soil/vegetation <sup>combination</sup> contribution?
- 2) What are the relative roles, in terms of scattering?
  - a) The leaves ?
  - b) The stalks ?
  - c) The fruits ?
  - d) The surface (in surface targets) ?
  - e) The volume ( within the surface) ?

APPROACHES: To understand the wave target interaction process, experiments need to be conducted and models developed in areas of:

- 1) Dielectric Properties
- 2) Attenuation Properties
- 3) Volume Geometry
- 4) Backscattering Properties
- 5) Emission Properties

MEASUREMENT TECHNIQUES:

- 1) Conventional Backscattering Measurements
- 2) Backscattering Measurements of Constituents \*
- 3) Range Probing Measurements
- 4) Canopy Attenuation Measurements
- 5) Active/Passive Measurements

BACKSCATTERING MEASUREMENTS OF CONSTITUENTS IN VEGETATION CANOPY:

- 1) Stalk Contribution to  $\sigma^0$
- 2) Leaves " " " 161
- 3) Fruits " " "

# TOOLS NECESSARY FOR PRECISE MEASUREMENTS:

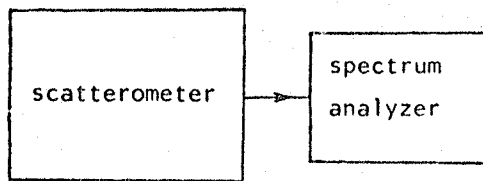
A volume probe which enables measurements of scattered energy from small portions of the target, such as leaves, stalks, etc.

## SYSTEM DESCRIPTION (Volume Probe):

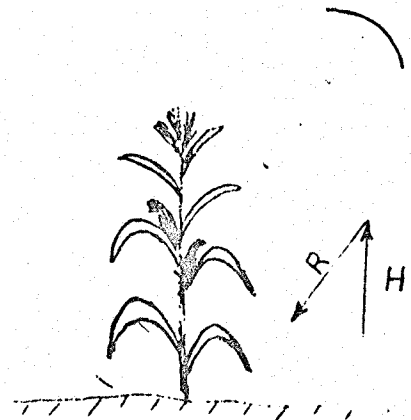
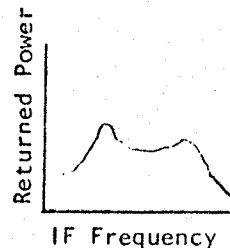
A fine-resolution short-range FM-CW radar scatterometer was used with the following specifications:

Operating Frequency:	10.0 GHz
Modulation:	Triangular
FM Rate (PRF):	150 Hz
RF Bandwidth:	2.25 GHz
IF Bandwidth:	300 Hz
Range Resolution:	6.67 cm
Antenna System:	Focused Horn Fed Parabolic Dish
Polarization:	Vertical (VV)
One-Way 3-dB Beamwidth:	2.5° in the Azimuth Plane 2.9° in the Elevation Plane
Focusing Range:	3.5 meters
Depth of Focus:	2.5 to 6.0 meters
Antenna Gain:	36 dB @ 10.0 GHz
Transmitt Power:	13 dBm @ 10.0 GHz

## MEASUREMENT PROCEDURES:



$$R = cF_{if} / 4F_m B$$



## TARGETS OBSERVED:

- 1) Crops: Corn, Milo, Wheat, Soybean
- 2) Surfaces: Concrete Walkways, Grass, Asphalt Pavements, Soil

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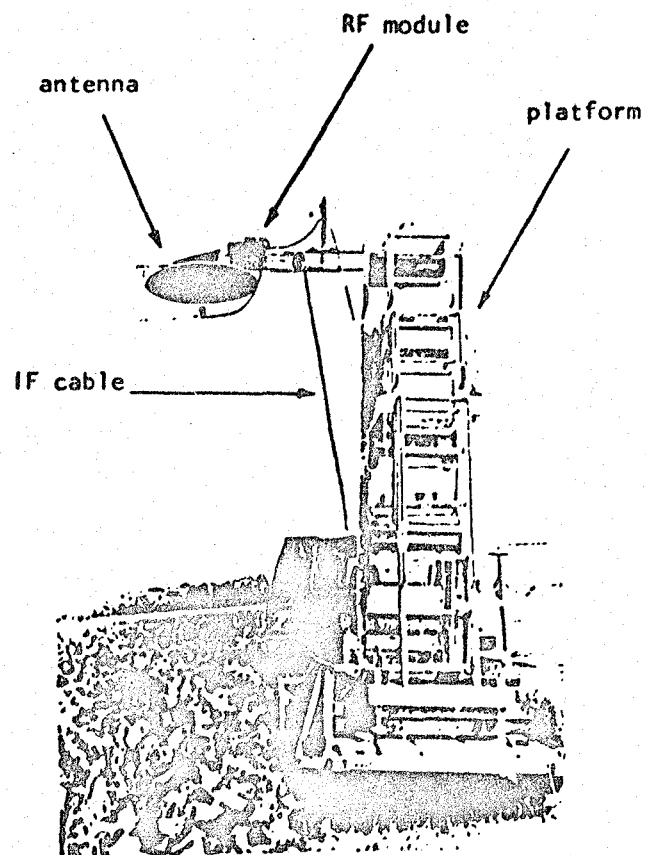


Figure 1. The antenna structure & various system components.

RESULTS: The results for the crops were obtained using defoliation experiments.

1) Immature corn (vertical):

- a) The cluster of leaves on top of the plant is the main backscattering source.
- b) Stalk has insignificant contribution to the backscatter.
- c) 22 dB loss due to the entire plant.

2) Mature corn (vertical):

- a) The cluster of leaves on top of the plant is the main backscattering source.
- b) The leaves around the cobs are the next main source.
- c) The tassel, cobs and stalk have insignificant contribution to the backscatter.
- d) 6 dB loss due to the entire plant.

3) Mature corn ( $30^\circ$  incidence angle):

- a) In the absence of leaves, backscattering is strongest at the lowest portion of the stalk and weakest at the top of the stalk.
- b) In the presence of leaves and stalks, backscatter from the leaves strongly dominates the total return.
- c) The cluster of leaves on top of the plant is the main backscattering source.

4) By comparison, it may be suggested that the top cluster of the leaves exhibit an isotropic backscattering pattern.

5) In all cases, most of the loss introduced by the plant, is due to the top leaves.

6) Backscattering from a corn leaf is about 15 dB higher at near-normal than near-grazing.

RESULTS: Milo plant.

1) Mature milo (vertical):

- a) The main backscattering source is the head of the Milo.
- b) The next major source is the combination of the leaves in the lower part of the plant.

Milo results cont.

- c) Contribution of the stalk to the backscatter is insignificant.
- d) 11 dB loss due to the entire plant (8 dB due to the head and 3 dB due to the leaves).

2) Mature milo ( $30^\circ$  incidence angle):

- a) The main backscattering source is the head of the milo.
- b) The backscattering from the head may be isotropic.
- c) The leaves laid in the plane of incidence showed weaker returns than the ones laid in the plane transverse to the plane of incidence. Further defoliation experiments are needed.

RESULTS: Wheat plant.

- 1) At vertical incidence, the top of the plant (where the head is located) and the cluster of the wheat stems near ground have stronger returns than the leaves and the middle stems.
- 2) At  $30^\circ$  incidence angle, the same results (as the above) were obtained. 6 dB loss was introduced as the transmitted energy passed through the plants. This loss was mostly due to the wheat heads.

RESULTS: Soybean plant.

- 1) The backscatter from nearly vertical measurements decreased as the penetration depth into the plant increased.
- 2) 17 dB loss due to the whole plant, and 14 dB of it was due to the lower half portion of the plant where the stems are.
- 3) At  $30^\circ$  incidence angle, the strongest backscatter was from the top leafy part of the plant.

RESULTS : Surface targets.

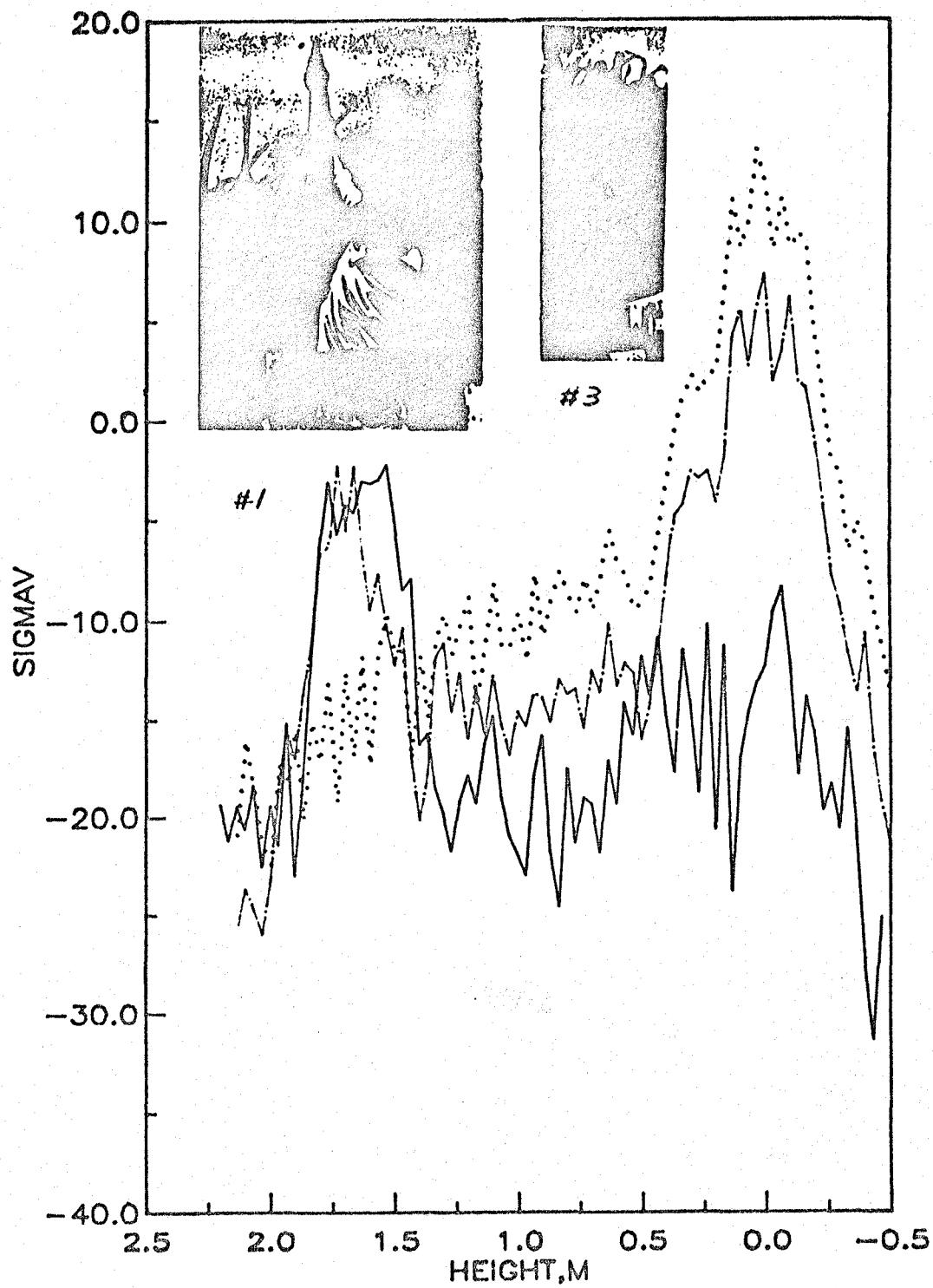
- 1) Concrete: Top surface, Bottom surface.
- 2) Grass: Blades, Soil surface.
- 3) Rough Soil: Top surface, Multiple scatter from clods, Volume scatter from clods, possibly soil volume scatter.
- 4) Asphalt #1: Top surface, Volume scatter from within the asphalt pavement
- 5) Asphalt #2: Top surface, Volume scatter from within the asphalt pavement, Bottom of the asphalt layer.

The incidence angle for the above targets:  $5^\circ$ ,  $5^\circ$ ,  $20^\circ$ ,  $20^\circ$ ,  $20^\circ$  respectively

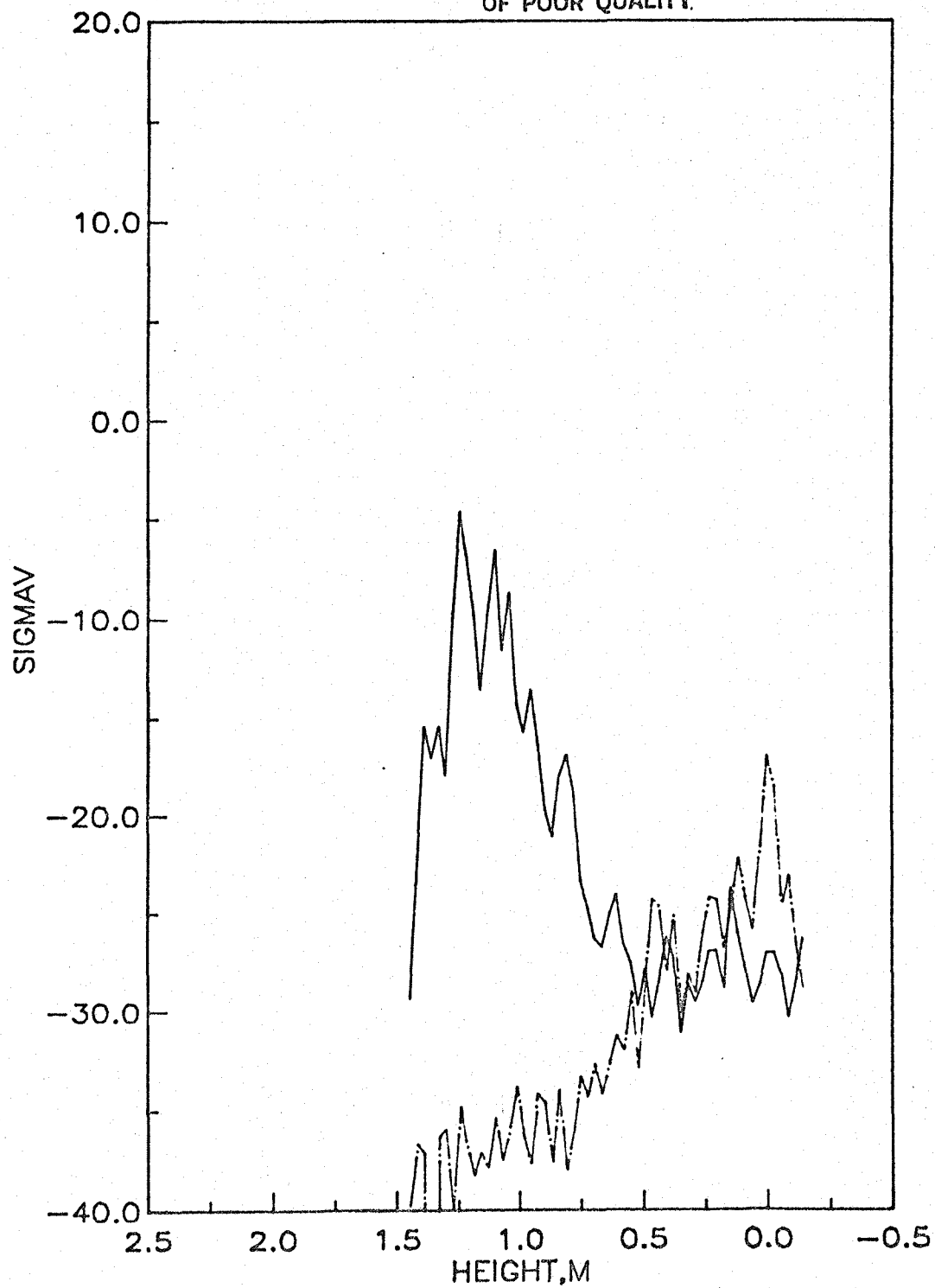


- ① —: full corn plant, —.—.—: 5 bottom leaves removed, .....: All leaves removed (only the stalk); (this plant was immature corn plant at section)
- ② —: stalk & leaves (corn), —.— only stalk
- ③ —: full Milo plant, —.—.—: leaves 7 & 8 removed, .....: leaves 5, 6 removed
- ④ —: full wheat (spot #1), —.—.—: full wheat (spot #2)
- ⑤ —: full soybean (spot #1), —.—.—: full soybean (spot #2)
- ⑥ —: full soybean, —.—.—: top  $\frac{1}{4}$  of the plant removed, ....: All the plant removed (ground return)

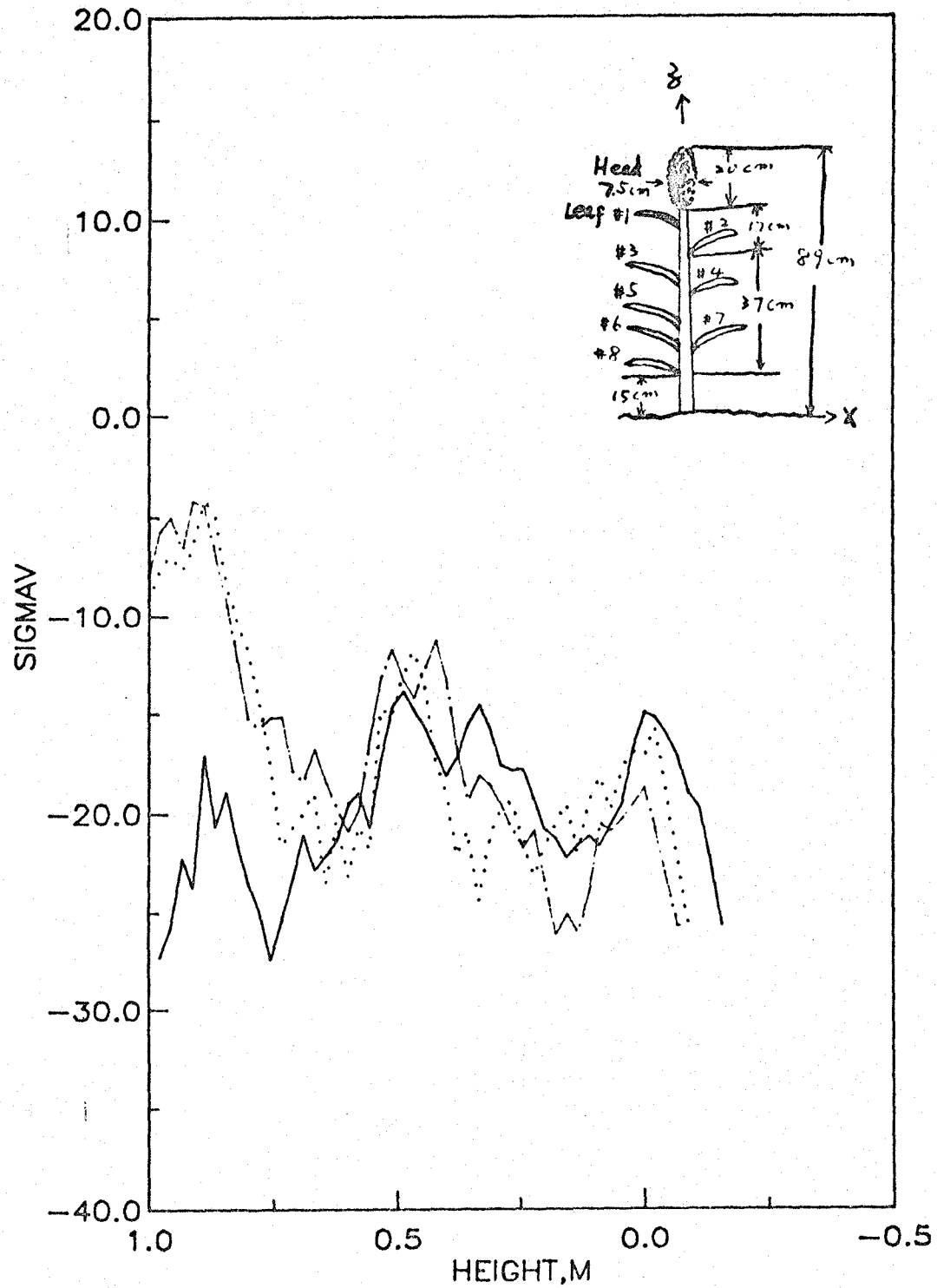
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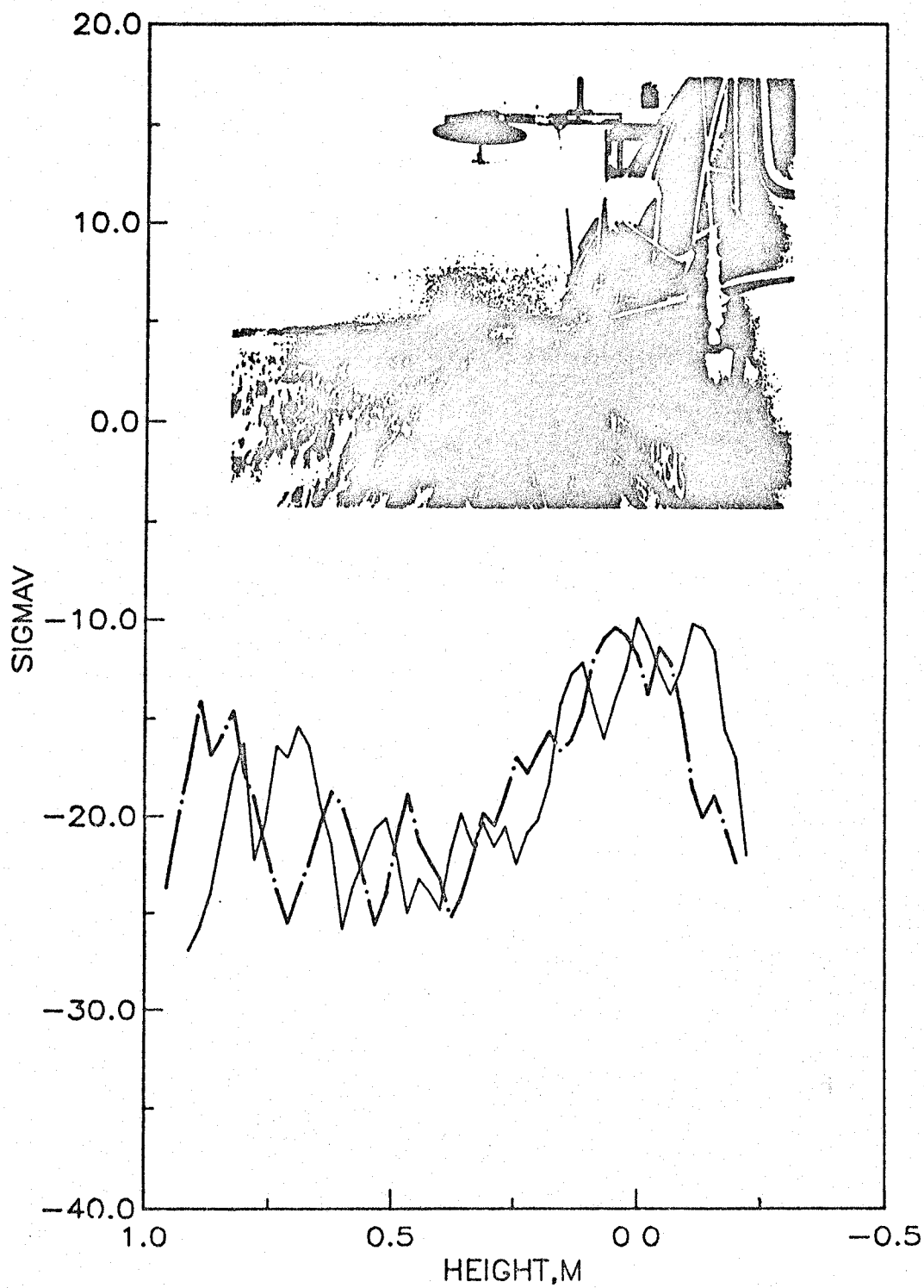
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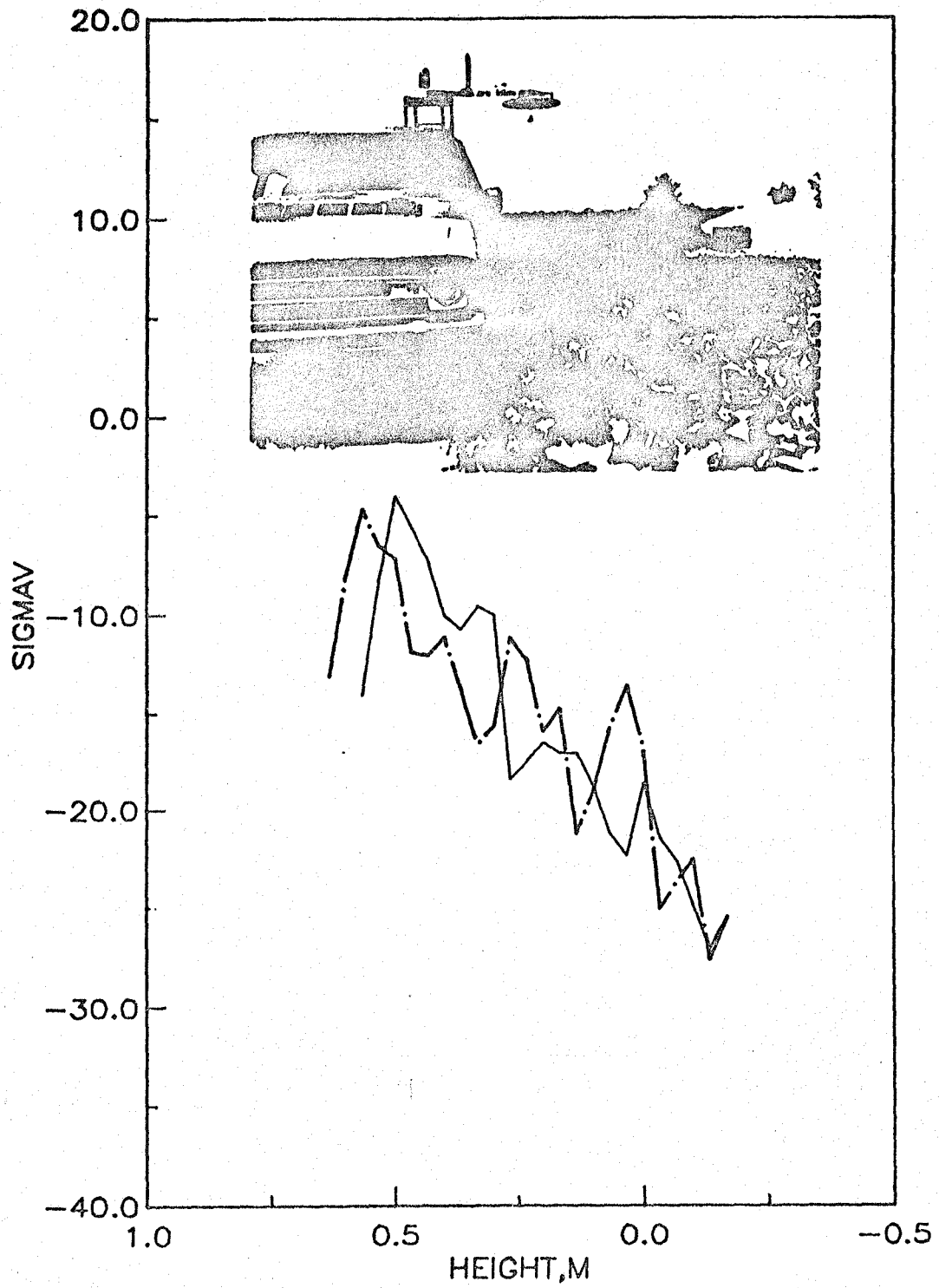
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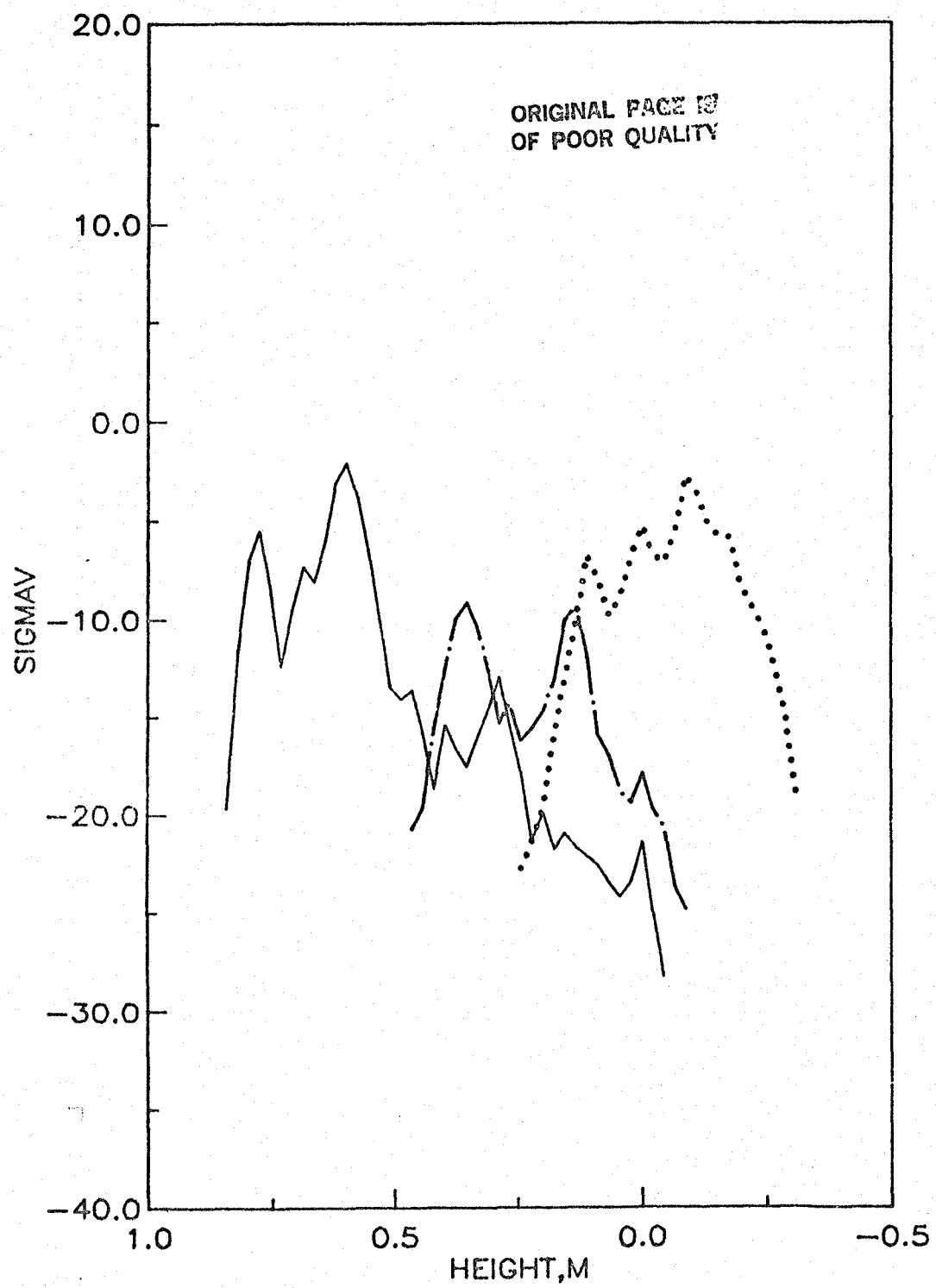


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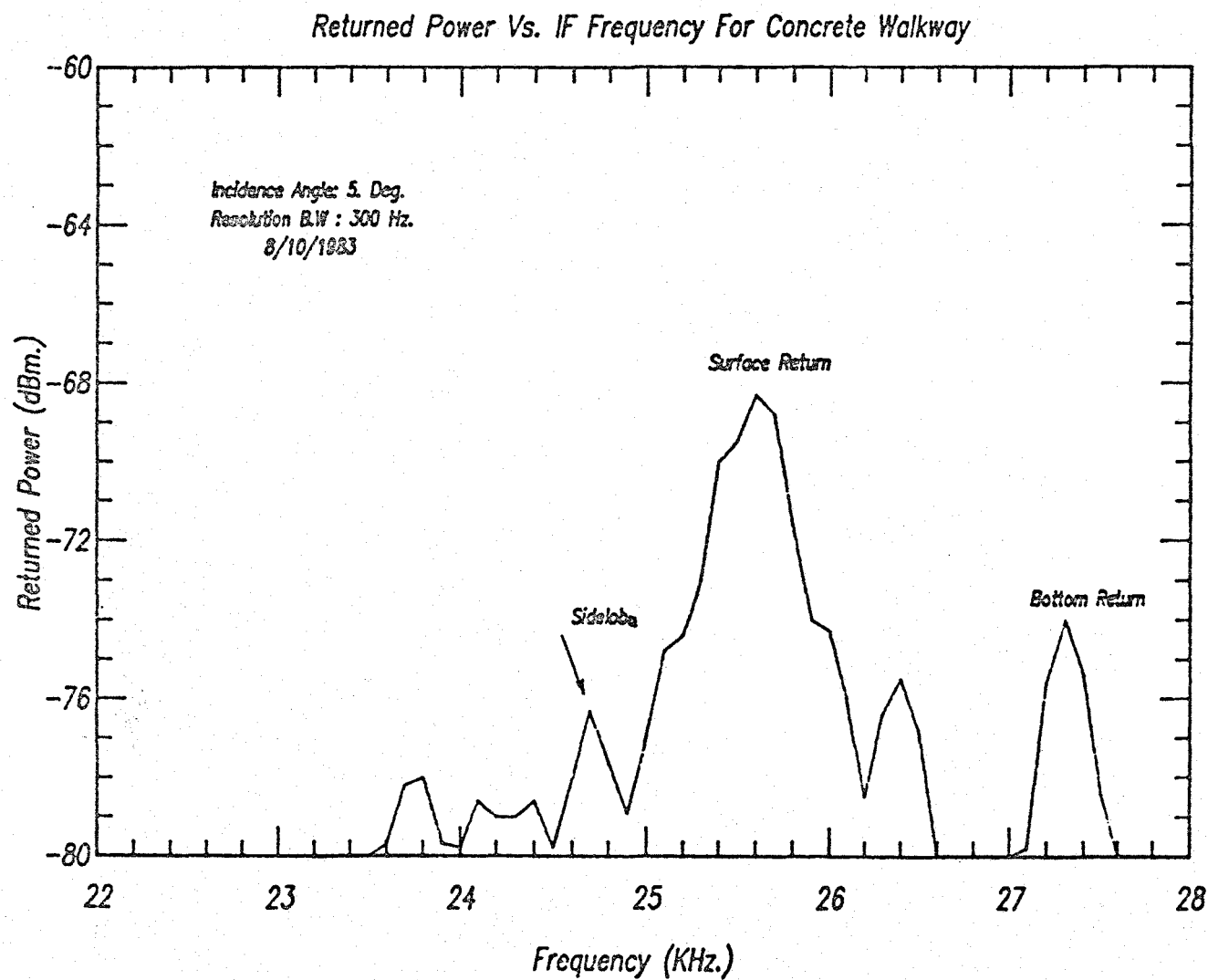
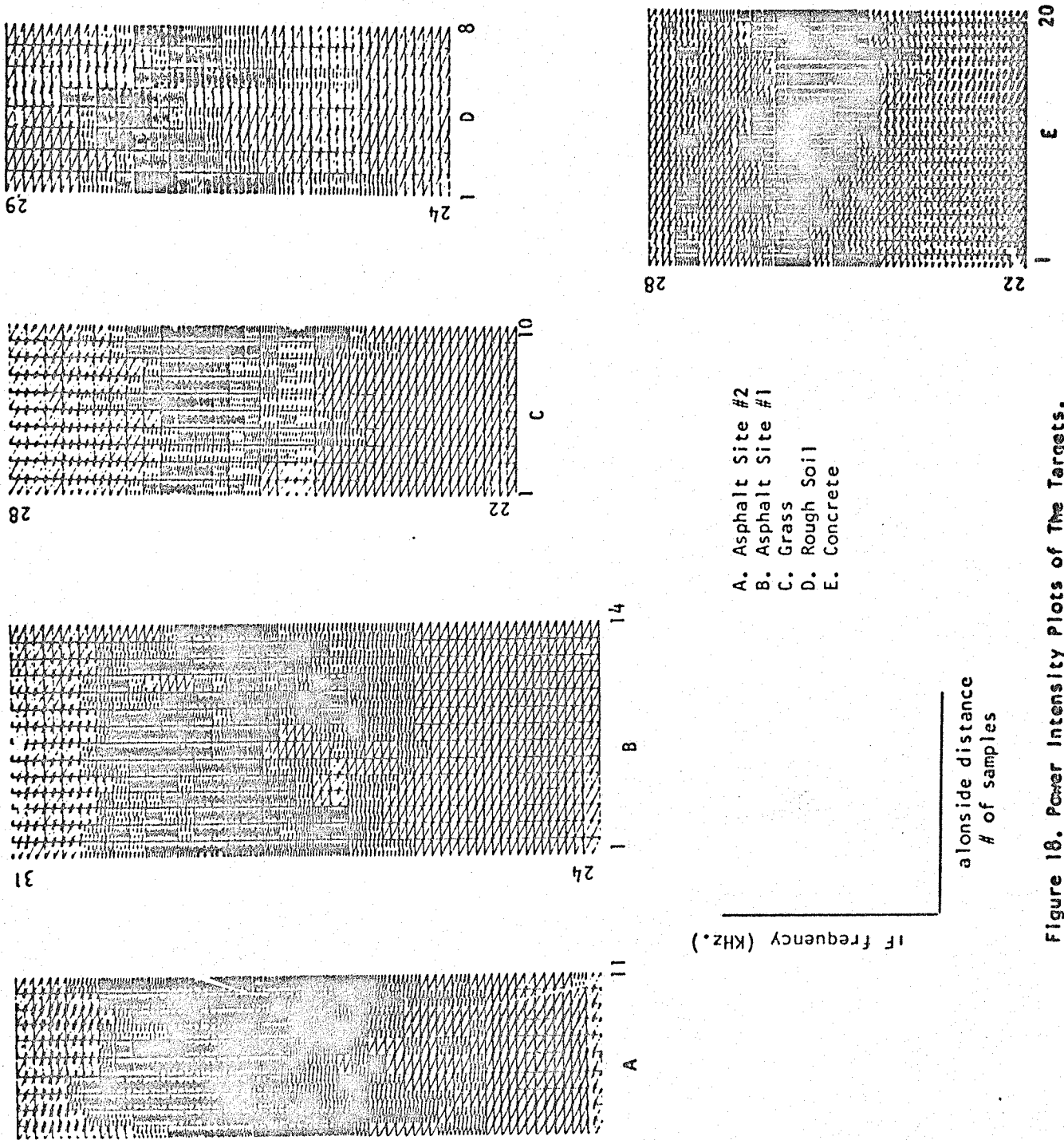


Figure 2

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- A. Asphalt Site #2
- B. Asphalt Site #1
- C. Grass
- D. Rough Soil
- E. Concrete

Figure 18. Power Intensity Plots of The Targets.

EFFECTS OF VEGETATION CANOPY STRUCTURE ON MICROWAVE SCATTERING

J. Paris  
NASA/JPL

ANNUAL REPORT  
EFFECTS OF VEGETATION CANOPY STRUCTURE  
ON MICROWAVE SCATTERING

- JACK F. PARIS (JET PROPULSION LAB.)
- BROAD GOAL: INCREASE UNDERSTANDING OF ROLE OF CANOPY STRUCTURE ON RADAR BACKSCATTERING BY VEGETATION & SOIL
- FIRST YEAR: DEVELOP MODELS THAT USE STRUCTURE EXPLICITLY AND PREPARE FOR EMPIRICAL FIELD EXPERIMENTS
- TECHNICAL PROGRESS:
  - 1. SINGLE-SCATTERING MODEL WAS DEVELOPED WITH POLARIZATION, ELEMENT SIZE, AND ELEMENT ORIENTATION AS PARAMETERS
  - 2. MODEL SENSITIVITY STUDIES WERE COMPLETED
  - 3. MODELS WERE TESTED AGAINST KU/ K8U CORN AND WHEAT DATA
  - 4. PREPARATION FOR FY84 FIELD STUDIES WAS STARTED

END

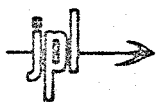


ANNUAL REPORT (J.F. PARIS) PAGE 2

8 SCIENTIFIC FINDINGS

1. MODEL FORM FOR CROSS POLARIZATION DIFFERS FROM THAT OF LIKE POLARIZATION
2. USE OF RATIOS OF BACKSCATTERING COEFFICIENTS CAN ISOLATE CANOPY ELEMENTS ORIENTATION FEATURES
3. 'THIN' CANOPY BACKSCATTER IS MOST AFFECTED BY EXTINCTION CROSS SECTION AND NUMBER OF ELEMENTS PER UNIT AREA
4. 'THICK' CANOPY BACKSCATTER IS MOST AFFECTED BY RATIO OF BACK SCATTERING AND EXTINCTION CROSS SECTIONS
5. CANOPY-SURFACE INTERACTION CAN ADD SIGNIFICANT BACKSCATTER
- \*\*6. USE OF EXPLICIT LEAF PROPERTIES LED TO SIGNIFICANT IMPROVEMENT IN GOODNESS OF FIT OF MODEL PREDICTIONS TO OBSERVATIONS (R2 INCREASED FROM .79 TO .93)

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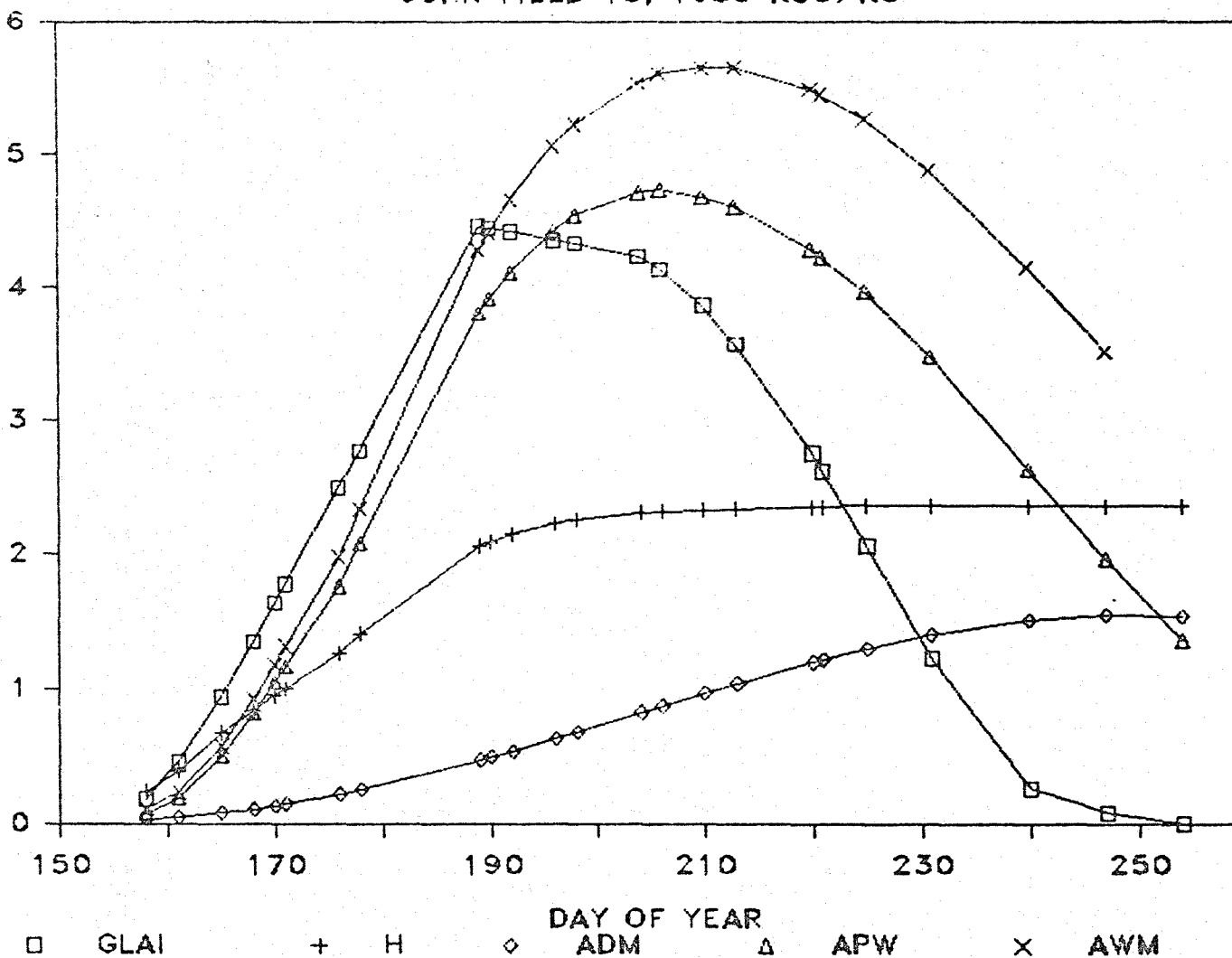


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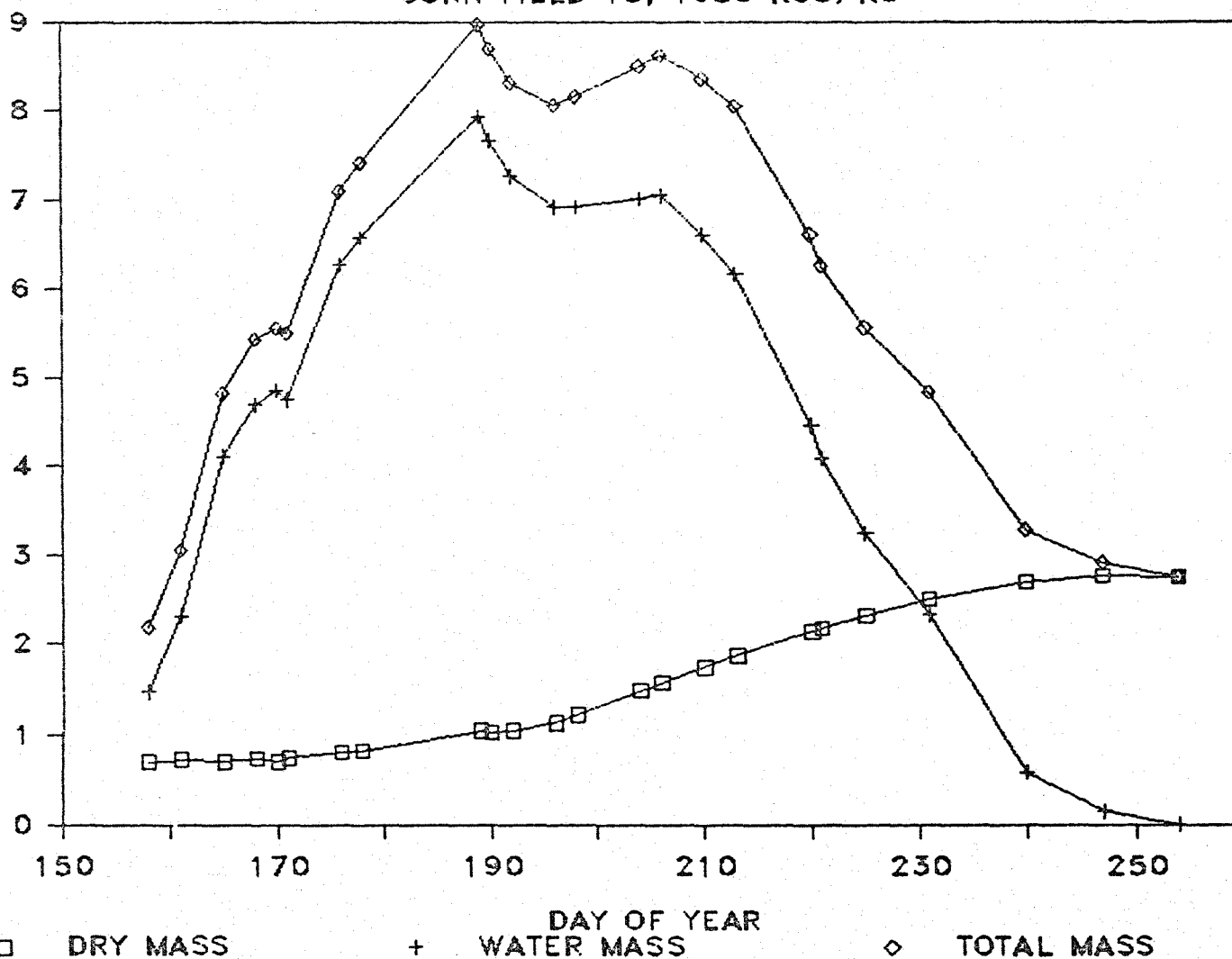




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MASS OF EACH LEAF (GM)



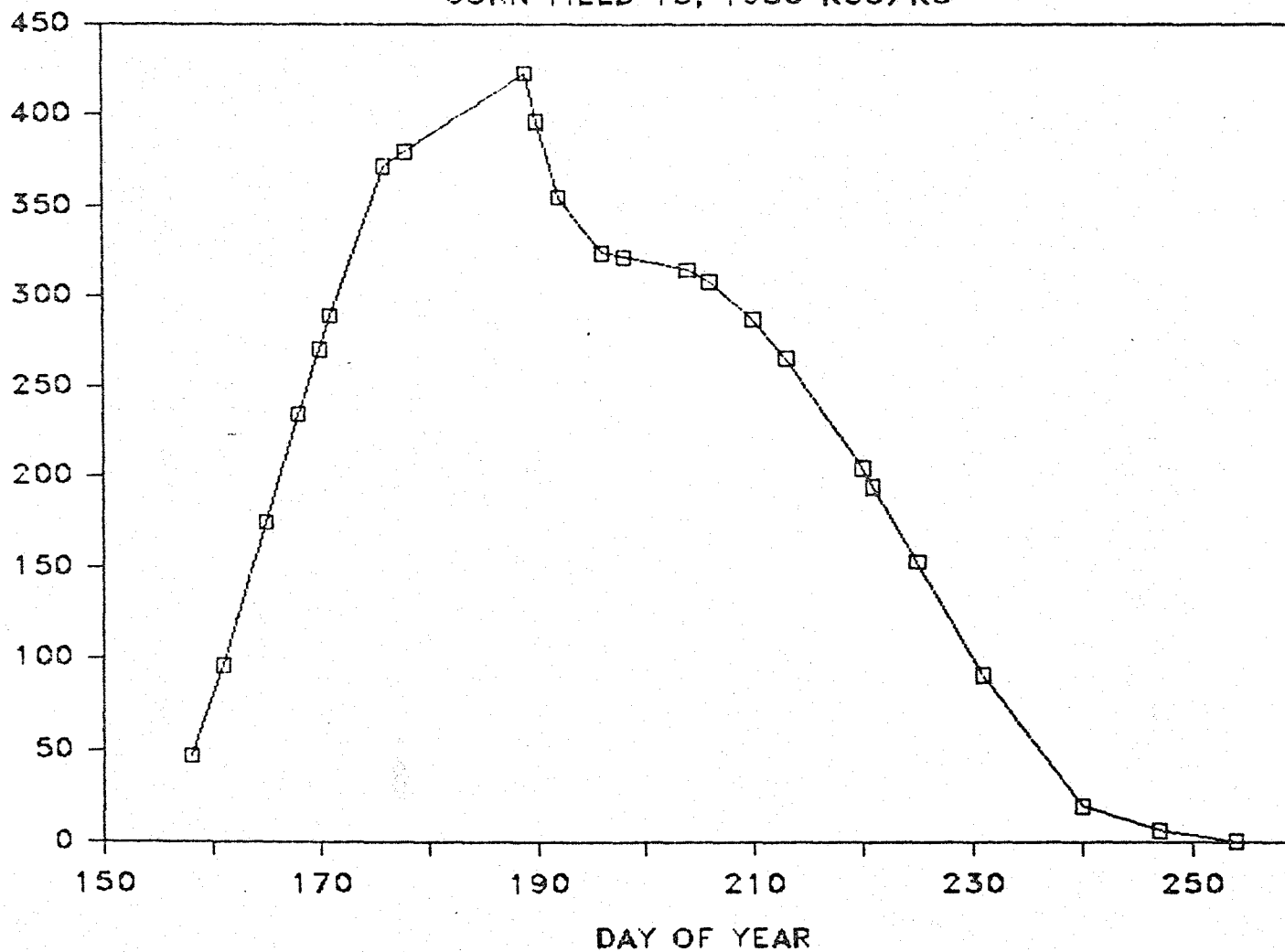
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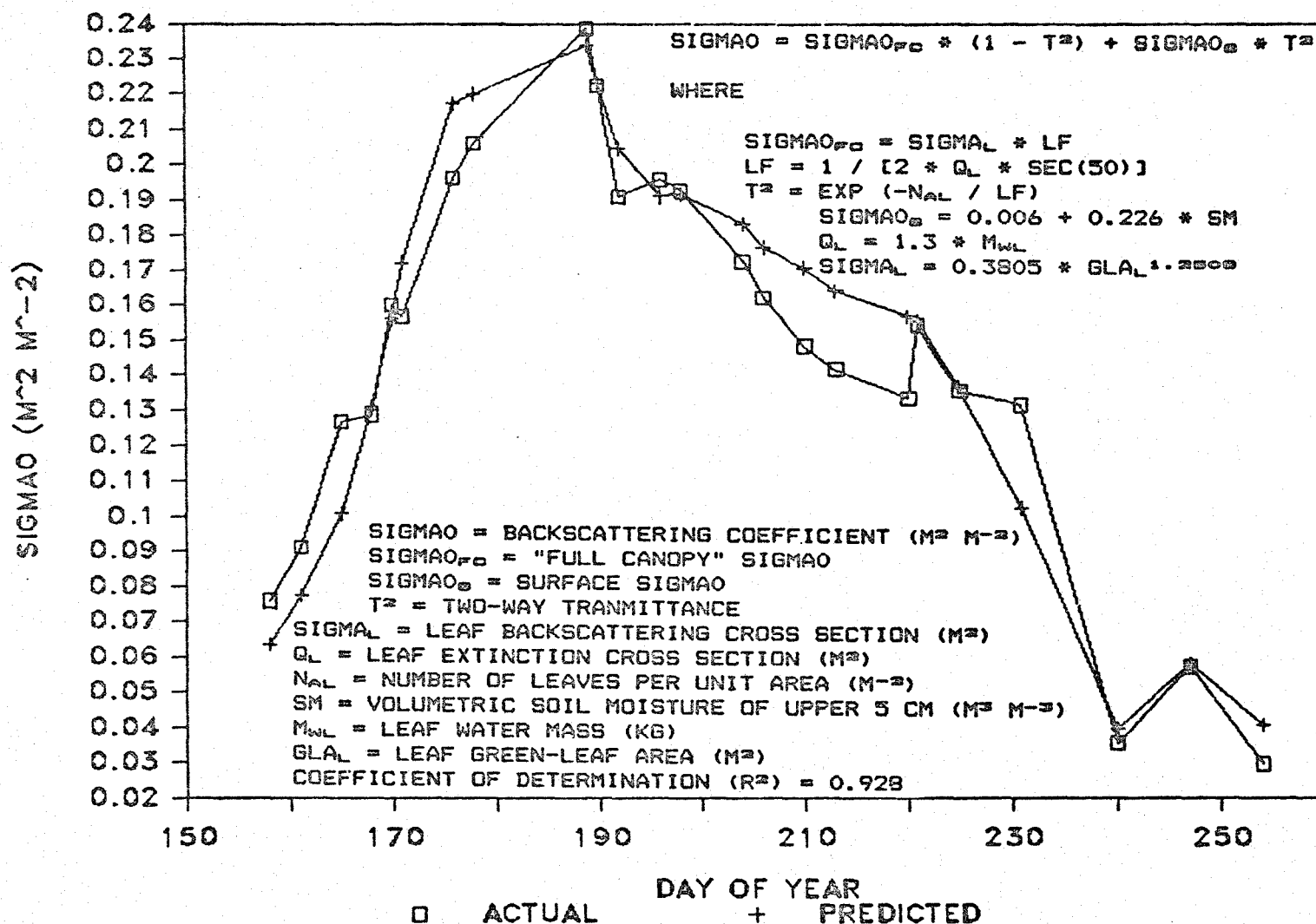
GREEN LEAF AREA (CM<sup>2</sup>)



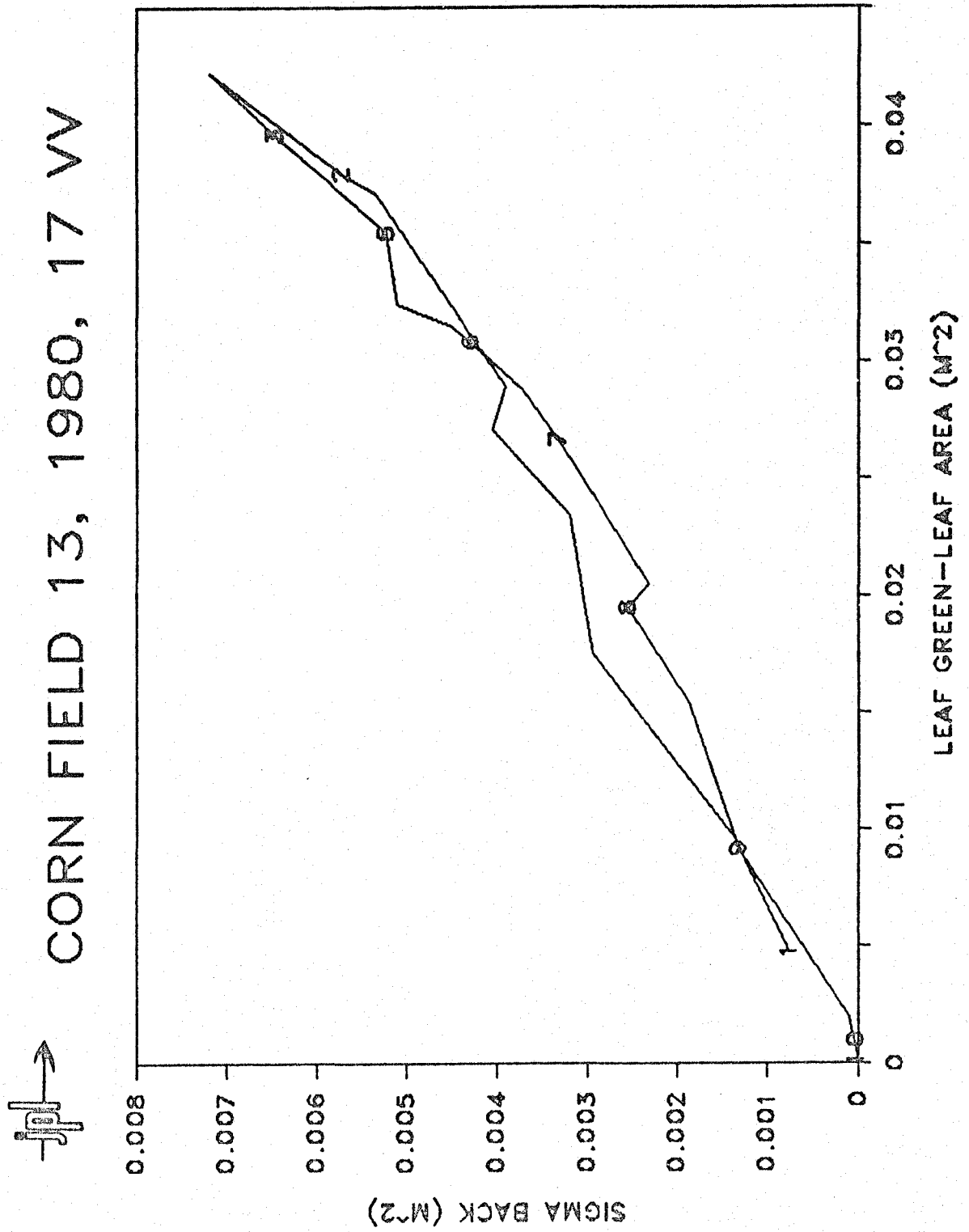
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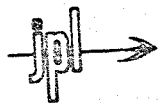
# CORN FIELD 13, 1980, 17 VV



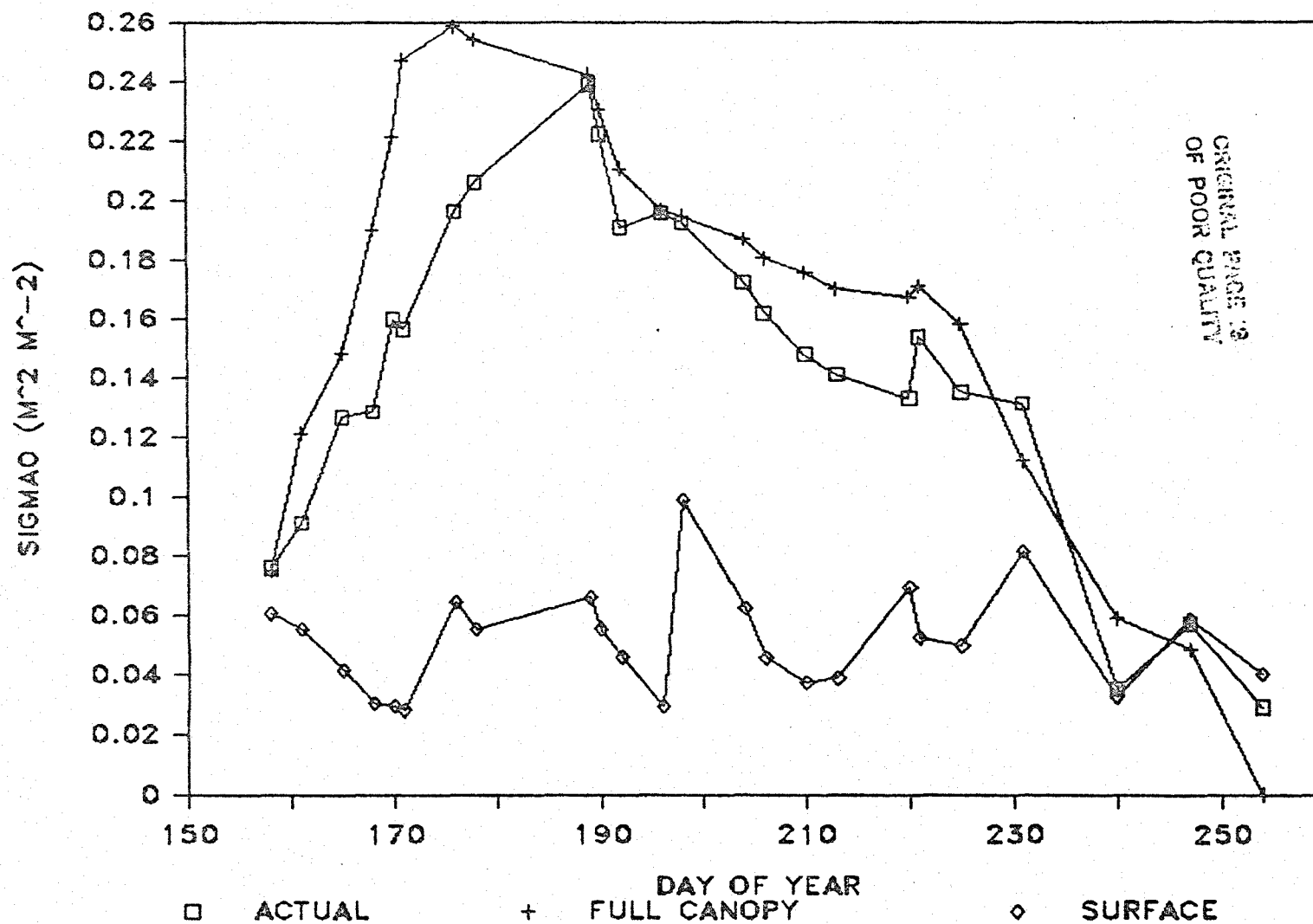
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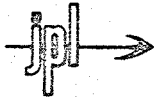






# CORN FIELD 13, 1980, 17 VV





● SIGNIFICANCE OF FINDINGS

1. NEW MODEL CAN BE USED TO ISOLATE CANOPY ELEMENT SIZE, ORIENTATION, AND WATER CONTENT FROM RADAR BACKSCATTERING
2. NEW MODEL CAN AID IN THE DESIGN OF FUTURE FIELD EXPERIMENTS

● RELATIONSHIP TO OTHER GRAEC STUDIES

1. KU TRANSMITTANCE MEASUREMENTS
2. KU SOURCES-OF-SCATTERING STUDY
3. GWU DISCRETE-ELEMENT SCATTERING STUDY

● SECOND (CURRENT) YEAR GOALS

1. IMPROVE MODEL TO INCLUDE MULTIPLE SCATTERING AND TO RESPONDE TO BIOPHYSICAL PARAMETERS
2. TEST MODEL AGAINST JPL RADAR SPECTROMETER DATA

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# PUBLICATIONS

Part 18, J.E., 1983: Radar backscattering  
properties of coral and mangrove at  
13.5 MHz. IEEE Trans. 35-21-400.  
Remote Sensing, 35-21-400.

Part 18, J.E., 1983: Effects of vegetation  
on radar backscattering. National Radio Sci.  
Meeting, Boulder, CO.

Part 18, J.E., 1983: On the use of  
polarized radar for forest  
classification. 1983 IEEE Trans.  
35-21-400. Also, Remote Sensing,  
35-21-400.

### III.C.3. ATMOSPHERIC EFFECTS STUDIES

- R. Fraser - Atmospheric Effect on Remote Sensing of the Earth's Surface
- W. Pearce - The Characterization of Surface Reflectance Variation Effects of Remote Sensing
- S. Gerstl - Multidimensional Modeling of Atmospheric Effects and Surface Heterogeneities on Remote Sensing
- D. Diner - Bidirectional Spectral Reflectance of Earth Resource: Influence of Scene Complexity and Atmospheric Effects on Remote Sensing

SEE D14

## ATMOSPHERIC EFFECTS ON REMOTE SENSING OF THE EARTH'S SURFACE

R. Fraser and Y. Kaufman  
NASA/GSFC

### ATMOSPHERIC EFFECT ON REMOTE SENSING OF THE EARTH'S SURFACE

#### BROAD GOALS

- O THEORETICAL INVESTIGATION OF THE MAIN CAUSES OF ATMOSPHERIC EFFECTS.
- O MEASUREMENT OF THE ATMOSPHERIC RADIATION PROPERTIES AND THEIR CORRELATION WITH AEROSOL PHYSICAL CHARACTERISTICS.
- O DEVELOPMENT OF ATMOSPHERIC MODELS THAT WILL ACCOUNT FOR THE MAIN ATMOSPHERIC EFFECTS.
- O DEVELOPMENT OF ATMOSPHERIC CORRECTION ALGORITHMS.

#### FIRST TWO YEARS OBJECTIVES

- O THEORETICAL STUDY OF THE RELATIVE IMPORTANCE OF THE AEROSOL SCATTERING, ABSORPTION, AND SIZE DISTRIBUTION IN REMOTE SENSING.
- O LABORATORY SIMULATION OF THE ATMOSPHERIC EFFECT AND COMPARISON WITH 3-D MODELS.
- O STUDY OF THE ATMOSPHERIC EFFECT ON THE SEPARABILITY BETWEEN FIELD CLASSES.
- O FIELD MEASUREMENT OF THE CORRELATION BETWEEN THE ATMOSPHERIC EFFECT AND THE ATMOSPHERIC AEROSOL CHARACTERISTICS.

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#### TECHNICAL PROGRESS AND ACCOMPLISHMENTS

- O THE FIRST THREE OBJECTIVES WERE ACCOMPLISHED AND SUMMARIZED (SEE PUBLICATIONS).
- O FIELD MEASUREMENTS WERE DESIGNED AND THE FIRST MEASUREMENTS TAKEN.

#### SCIENTIFIC FINDINGS AND SIGNIFICANCE TO THE GENERAL RESEARCH

- O AEROSOL ABSORPTION HAS A SIGNIFICANT EFFECT ON REMOTE SENSING MAINLY FOR HIGH SURFACE REFLECTANCES ( $R = 0.3$ ). AEROSOL ABSORPTION IS NOT KNOWN ACCURATELY; BUT FOR MODERATE VALUES, IT HAS TO BE ACCOUNTED FOR IN MODELLING AND CORRECTION ALGORITHMS.
- O REMOTE SENSING OF CONTRAST, SUCH AS THE VEGETATION INDEX, IS ONLY WEAKLY AFFECTED BY AEROSOL ABSORPTION BUT IS AFFECTED BY AEROSOL SCATTERING.
- O THE ATMOSPHERIC ADJACENCY EFFECT (EFFECT OF A BRIGHT FIELD ON THE APPARENT REFLECTIVITY OF A NEARBY DARK FIELD) HAVE BEEN VERIFIED EXPERIMENTALLY IN THE LABORATORY AND FIELD. THESE MEASUREMENTS ARE USED TO TEST THEORETICAL MODELS.
- O THE ADJACENCY EFFECT WAS SHOWN TO REDUCE THE SEPARABILITY BETWEEN FIELD CLASSES (IN ADDITION TO ITS EFFECT ON SPATIAL RESOLUTION AND CLASSIFICATION ACCURACY).

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RELATIONSHIP TO OTHER FUNDAMENTAL RESEARCH SRAEC INVESTIGATIONS

- o THIS INVESTIGATION IS RELATED TO THE ATMOSPHERIC STUDIES THAT AIM TO DEVELOP MODELS OF ATMOSPHERIC RADIATIVE TRANSFER AND TO PARAMETERIZE THE ATMOSPHERIC EFFECTS.

NEXT YEAR OBJECTIVES

- o DEVELOP PROCEDURES TO MEASURE THE AEROSOL SCATTERING AND THE AEROSOL ABSORPTION FROM SATELLITE DATA AND TEST THEM AGAINST VALUES DERIVED FROM SURFACE OBSERVATIONS.
- o DEVELOP AN ATMOSPHERIC CORRECTION ALGORITHM THAT IS BASED ON THE MEASURED PARAMETERS. APPLY THE CORRECTION TO SATELLITE OR AIRCRAFT DATA AND COMPARE WITH IN SITU MEASUREMENTS.
- o ANALYZE THE FIELD MEASUREMENTS OF THE CORRELATION BETWEEN THE ATMOSPHERIC EFFECT AND THE ATMOSPHERIC AEROSOL CHARACTERISTICS.

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STUDY PARTICIPANTS

PRINCIPAL INVESTIGATOR:

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CO-INVESTIGATOR:

DR. YORAM J. KAUFMAN  
UNIVERSITY OF MARYLAND AND  
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PUBLICATIONS (SRAEC SUPPORTED RESEARCH)

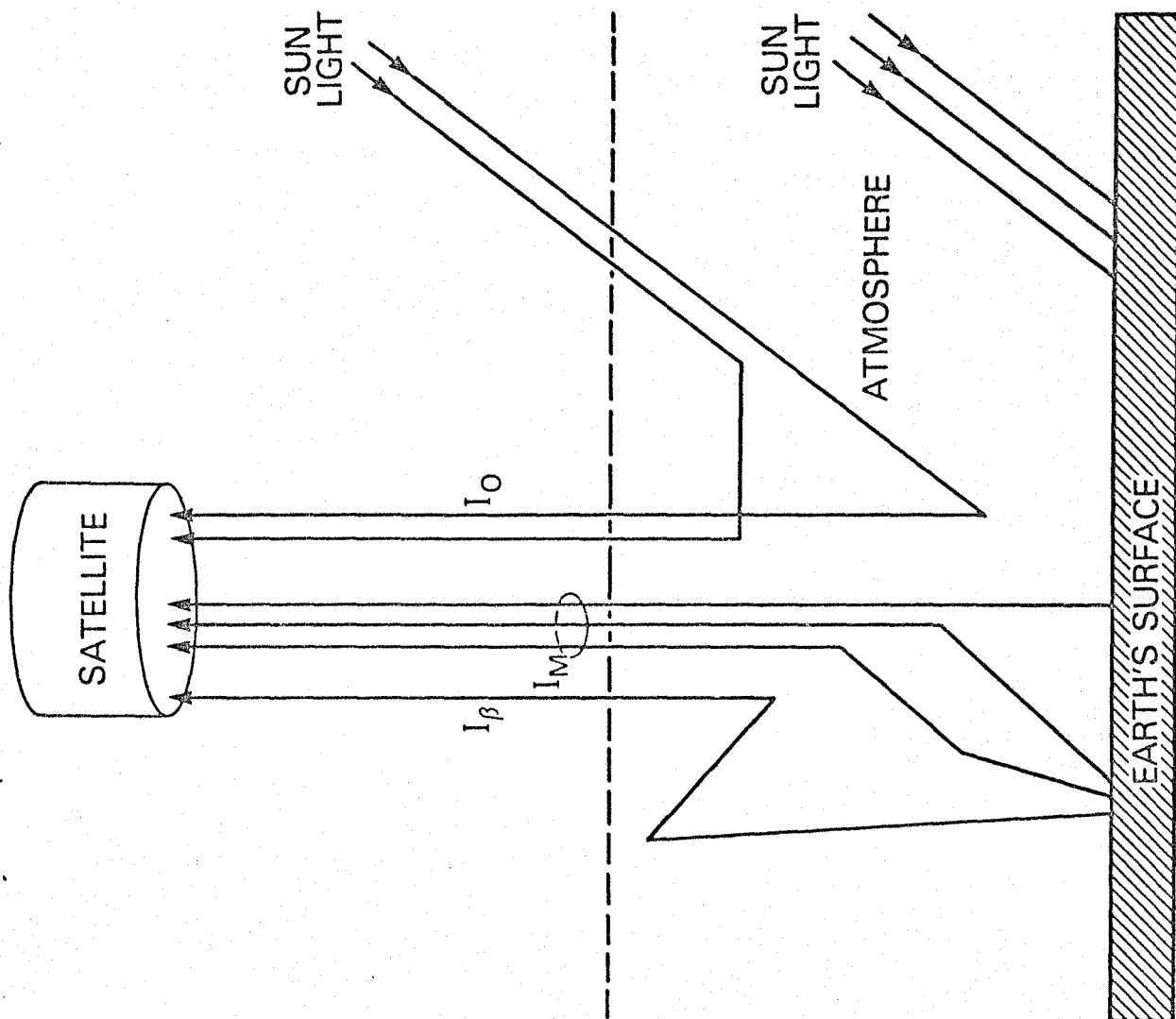
- 1) YU. MEKLER, Y. J. KAUFMAN, AND R. S. FRASER, 1983, REFLECTIVITY OF THE  
ATMOSPHERE-INHOMOGENEOUS SYSTEM. LABORATORY SIMULATION, IN PREPARATION, TO BE SUBMITTED TO  
J. ATMOS. SCI.
- 2) R. S. FRASER AND Y. J. KAUFMAN, 1983, THE RELATIVE IMPORTANCE OF AEROSOL SCATTERING AND  
ABSORPTION IN REMOTE SENSING, V CONF. ON ATMOS. RAD., BALTIMORE, MD.
- 3) Y. J. KAUFMAN AND R. S. FRASER, 1983, DIFFERENT ATMOSPHERIC EFFECTS IN REMOTE SENSING OF  
UNIFORM AND NONUNIFORM SURFACES, ADV. SPACE RES., 2, 147-155.

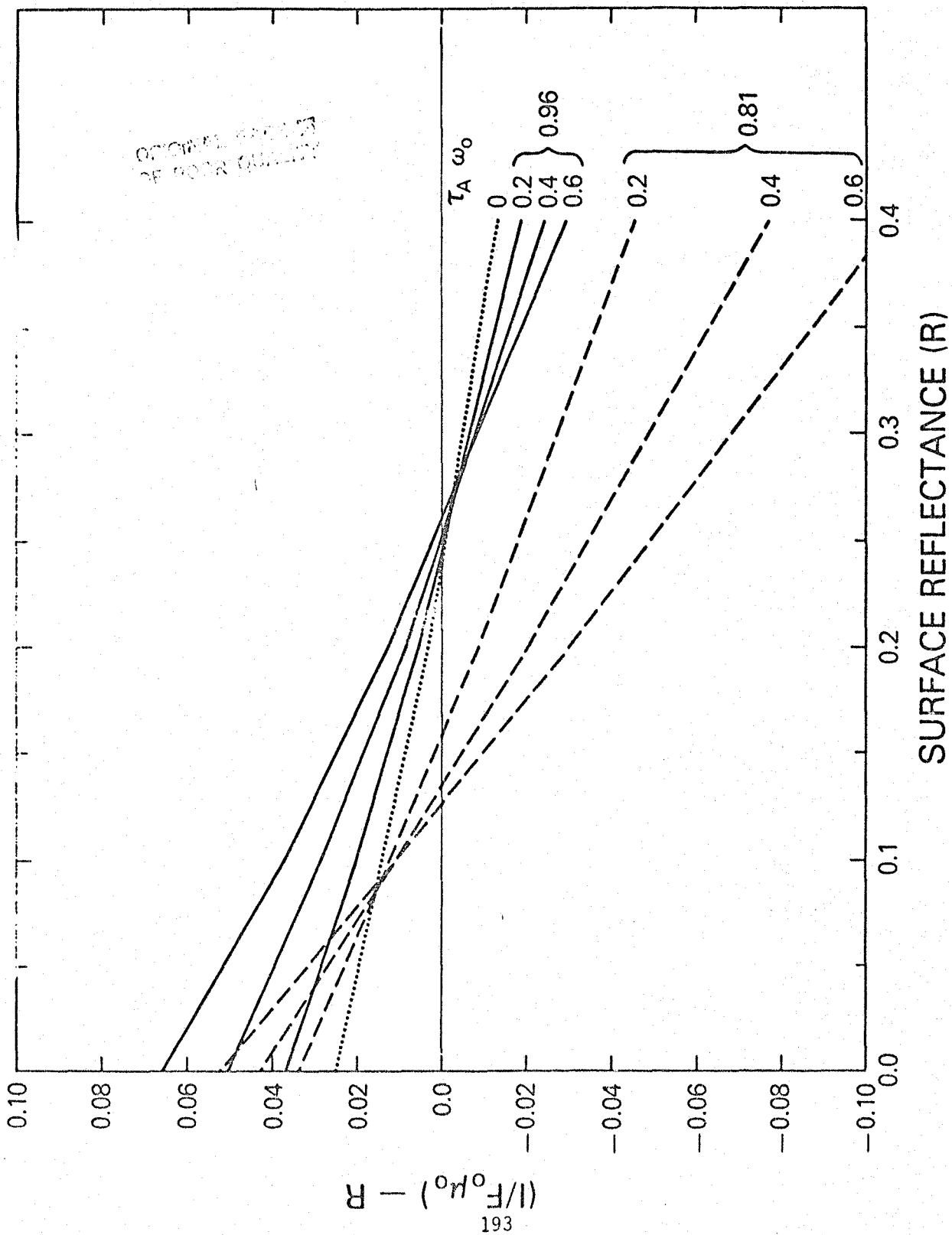


PUBLICATIONS (SRAEC PARTIALLY SUPPORTED RESEARCH)

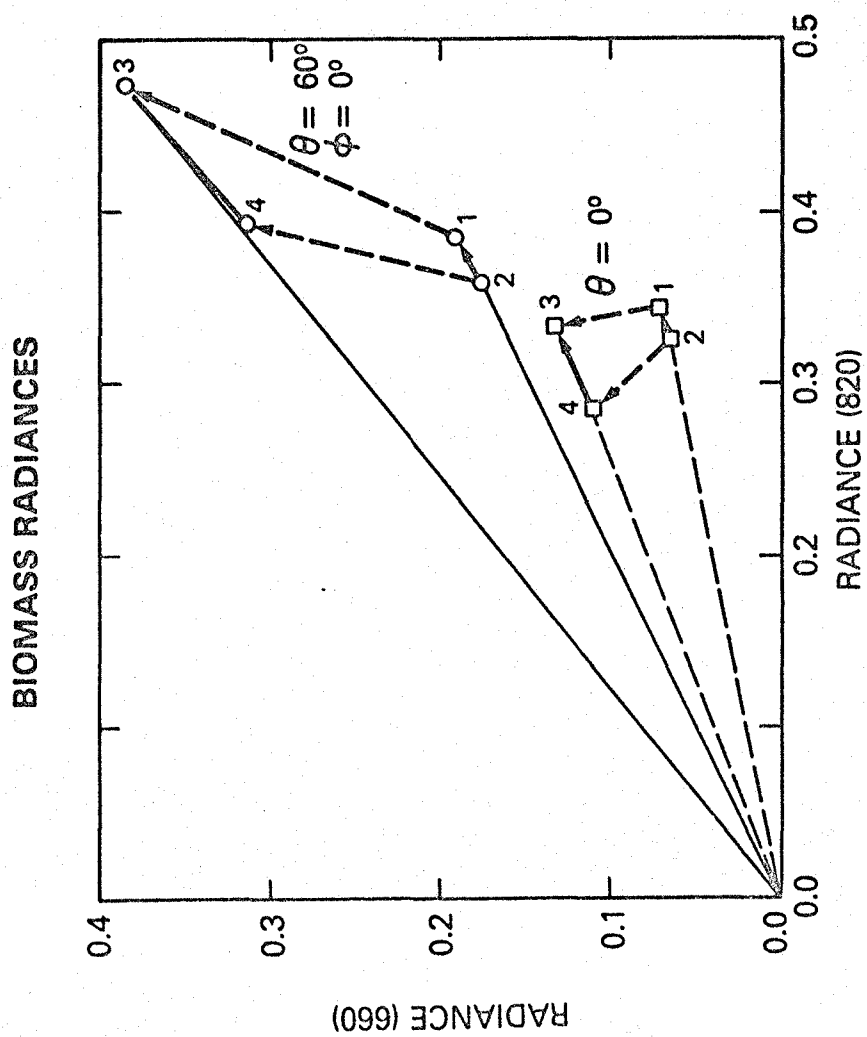
- 4) Y.J. KAUFMAN AND R. S. FRASER, 1983, THE ATMOSPHERIC EFFECT ON CLASSIFICATION OF FINITE FIELDS, ACCEPTED FOR PUBLICATION IN REM. SENS. OF ENVIR.
- 5) Y. J. KAUFMAN, T. W. BRAKKE, AND E. ELORANTA, 1983, FIELD EXPERIMENT TO MEASURE THE RADIATIVE CHARACTERISTICS OF A HAZY ATMOSPHERE, V. CONF. ON ATM. RAD., BALTIMORE, MD.
- 6) Y. J. KAUFMAN AND R. S. FRASER, 1983, ATMOSPHERIC EFFECT ON SEPARABILITY OF FIELD CLASSES, IN PREPARATION TO BE SUBMITTED TO INT. J. OF REM. SENS.
- 7) Y. J. KAUFMAN, 1983, ATMOSPHERIC EFFECT ON SPATIAL RESOLUTION OF SURFACE IMAGERY, SUBMITTED FOR PUBLICATION TO APPLIED OPTICS.

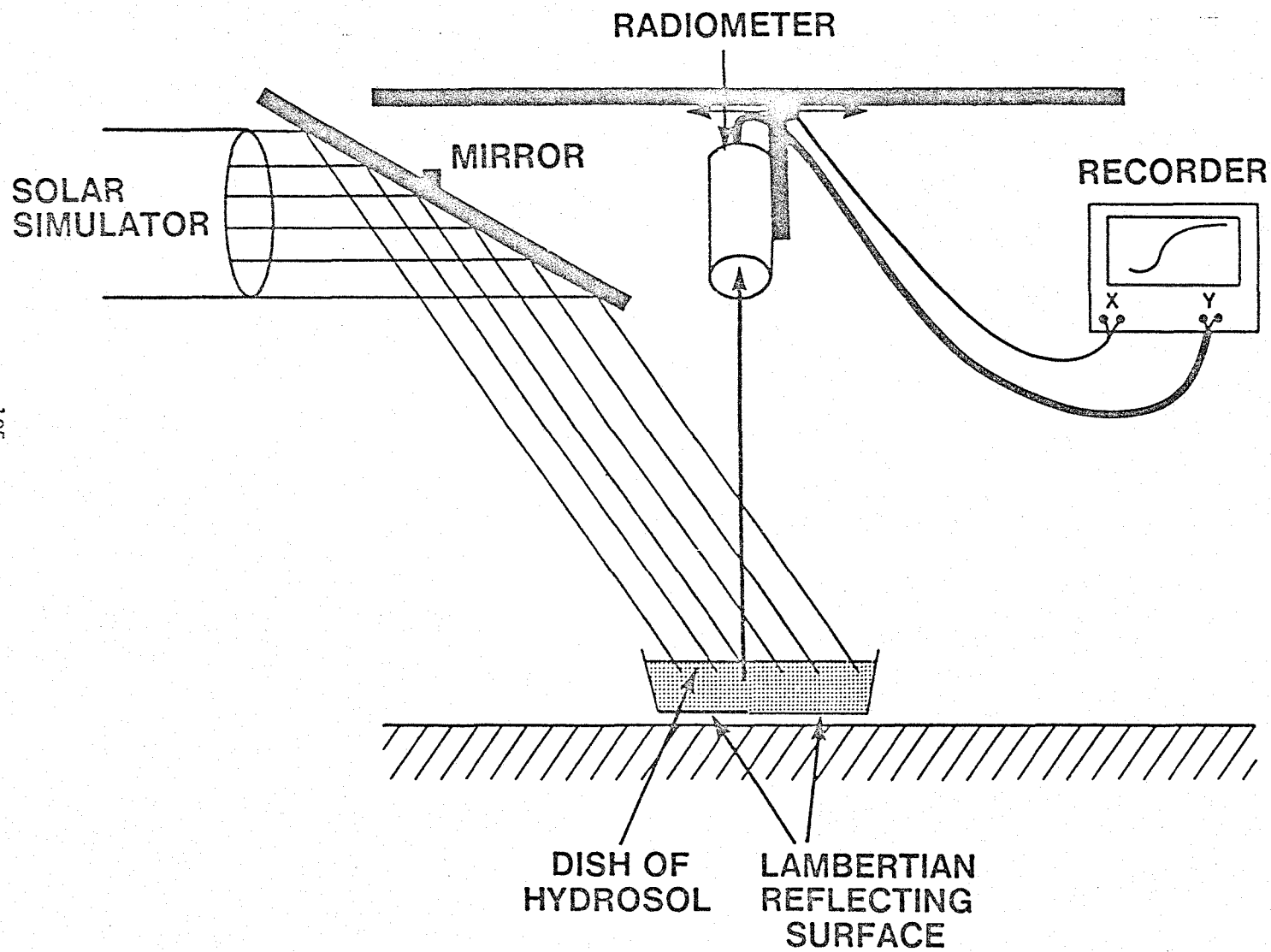
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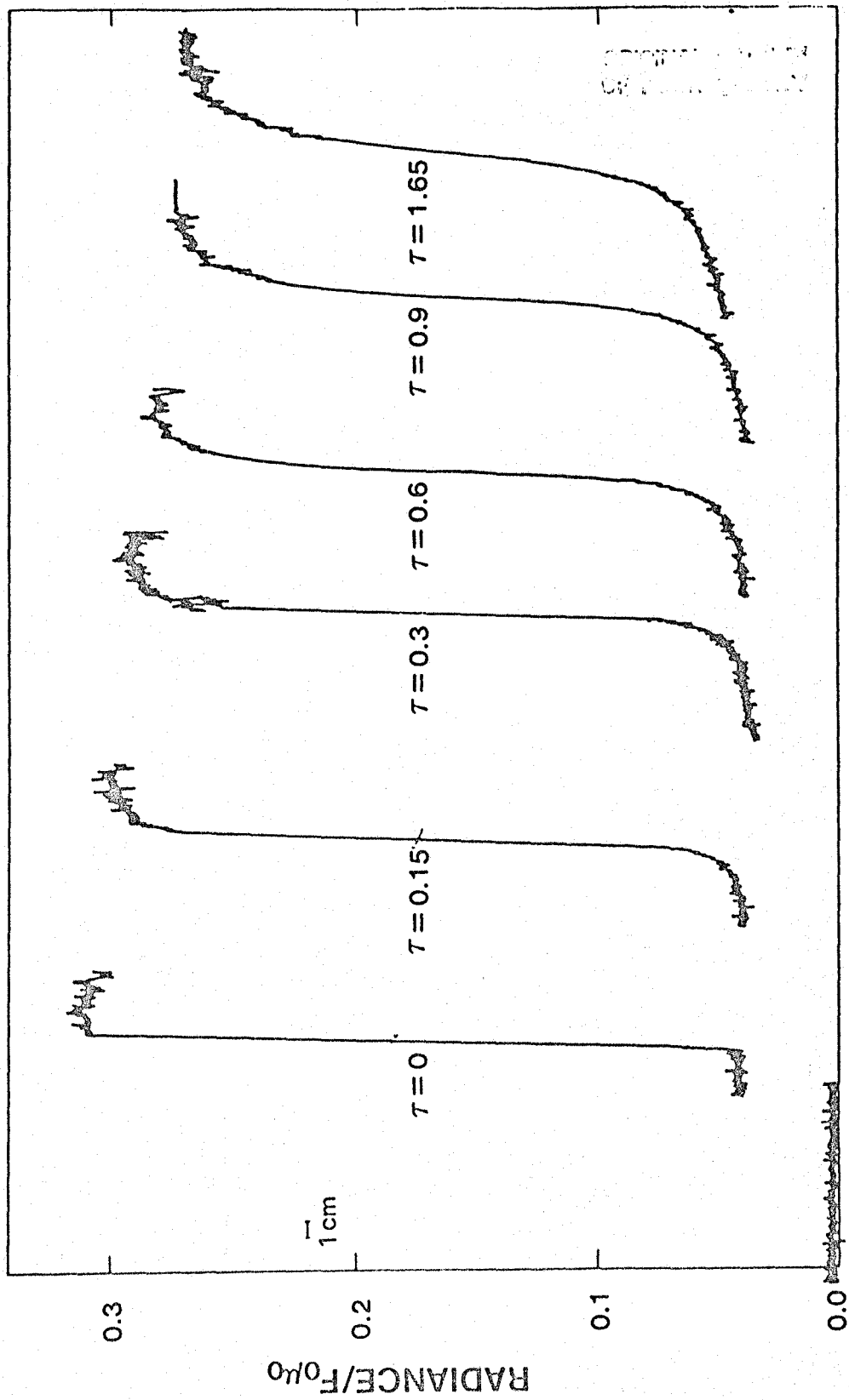


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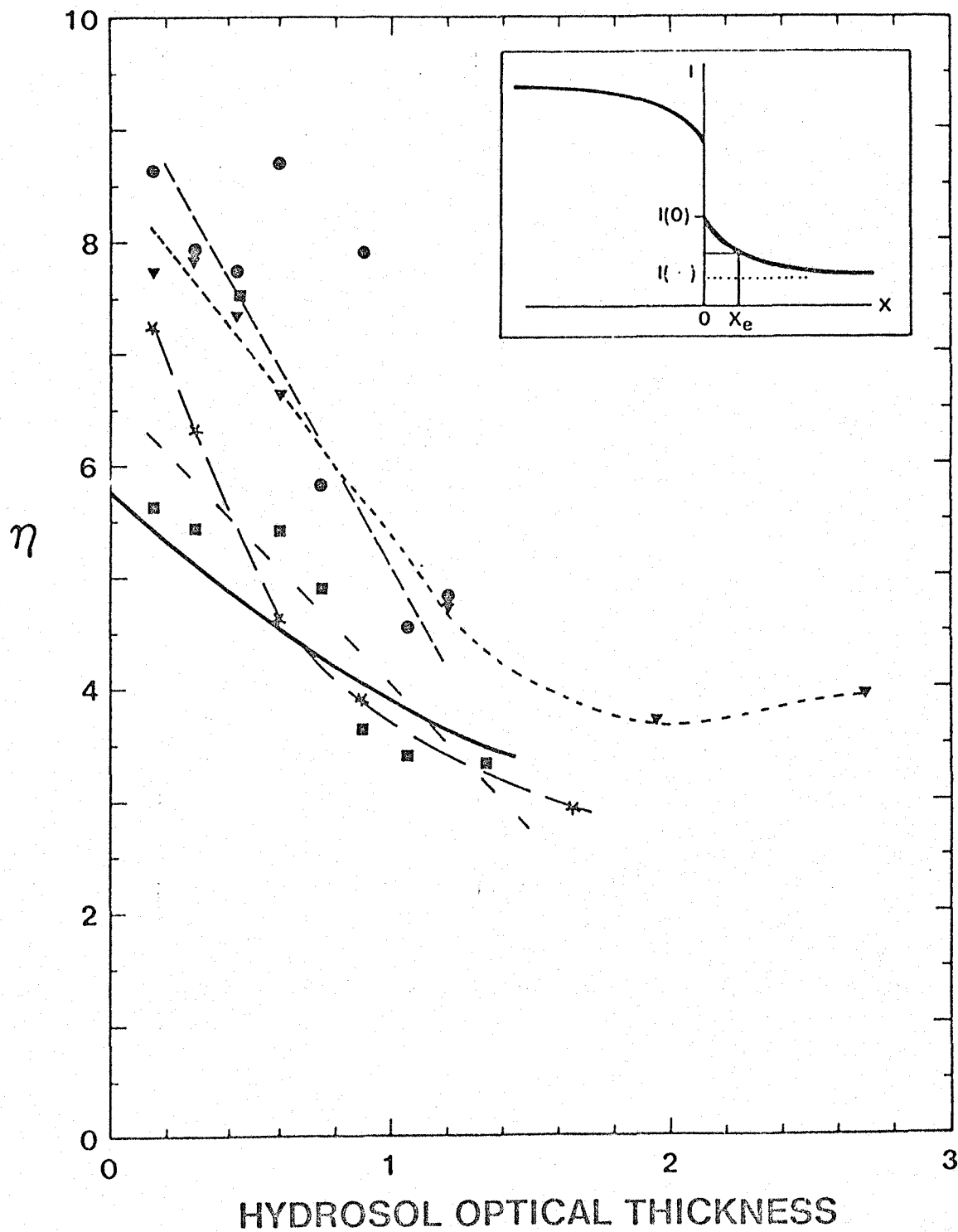




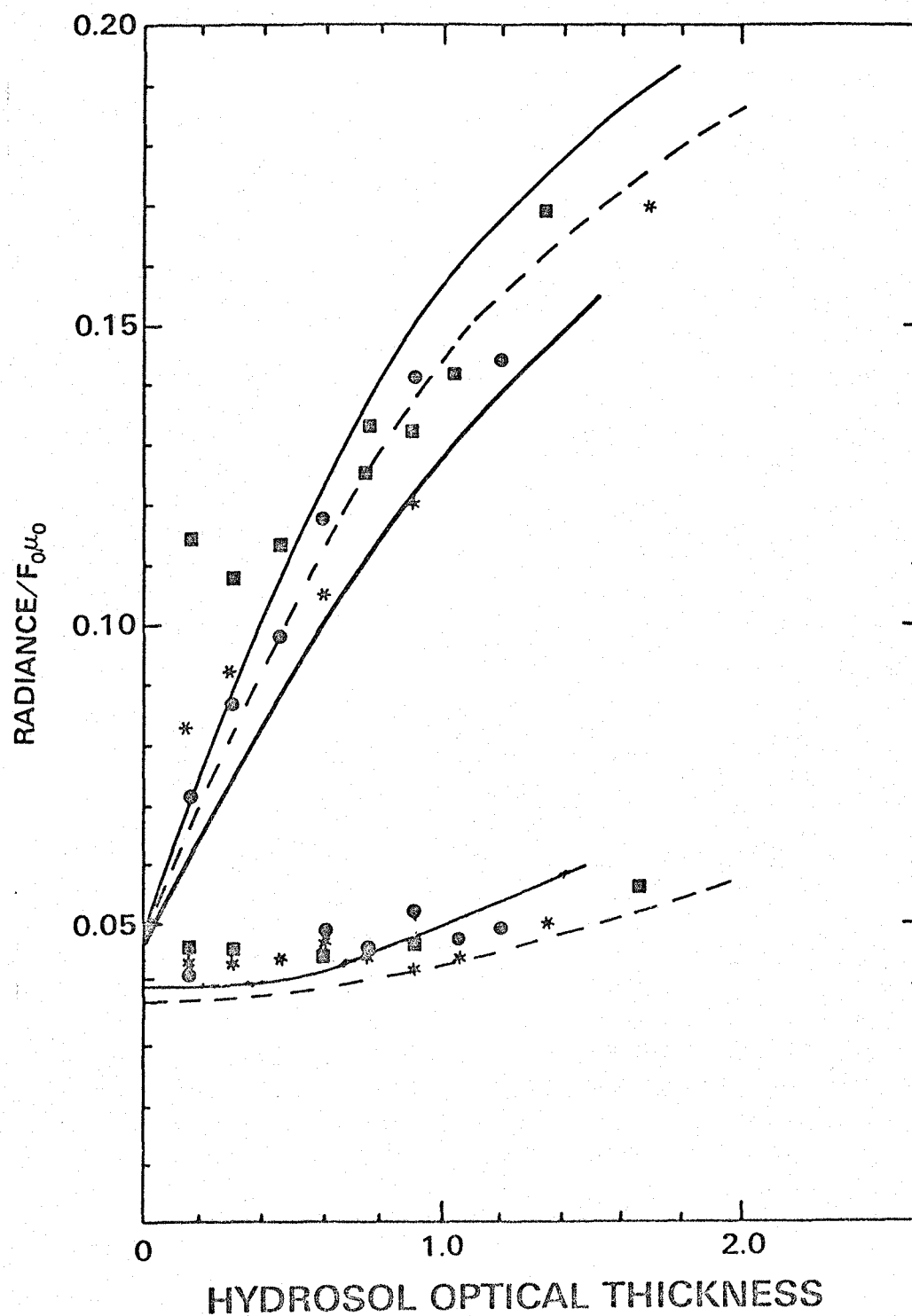
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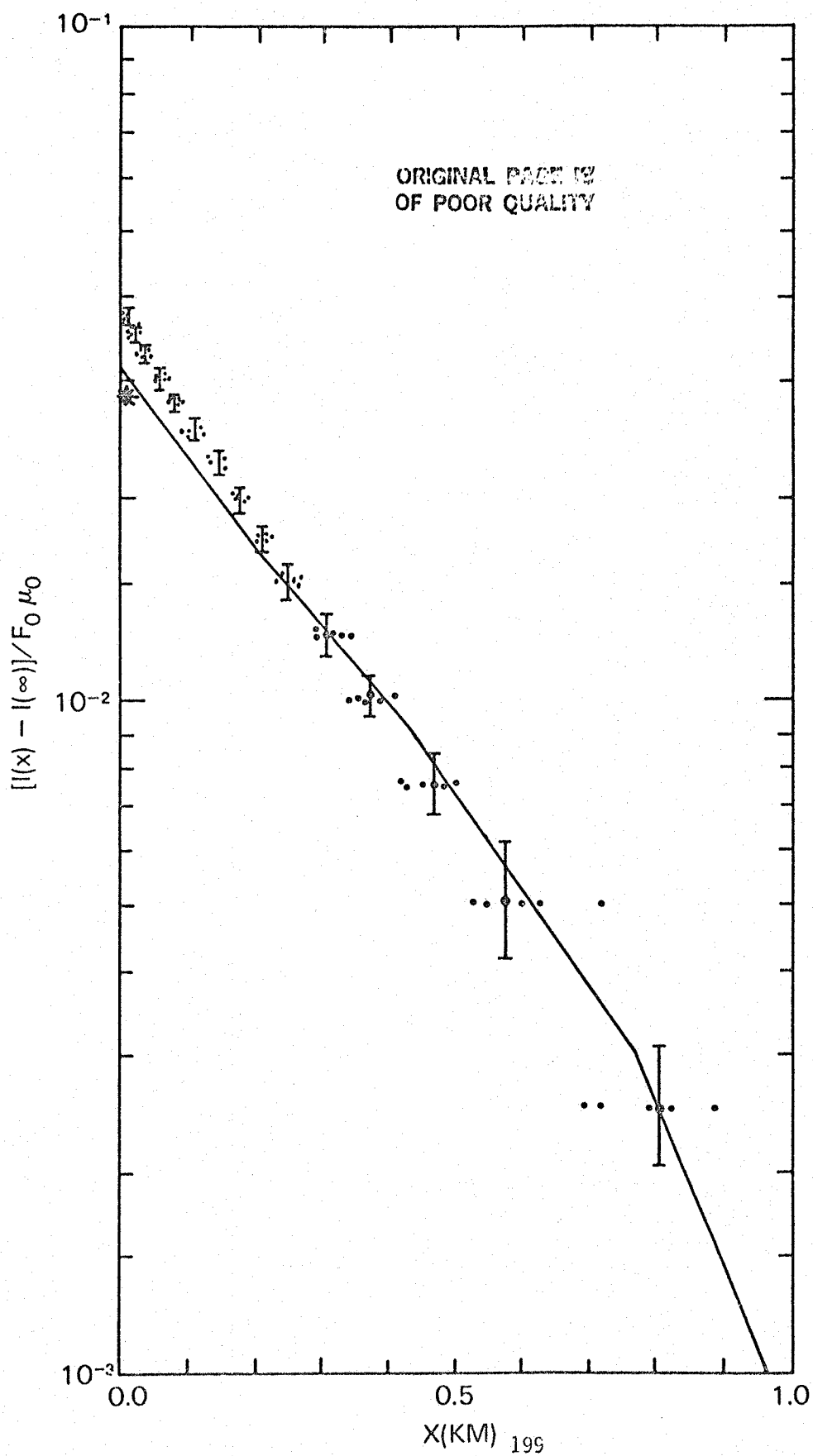
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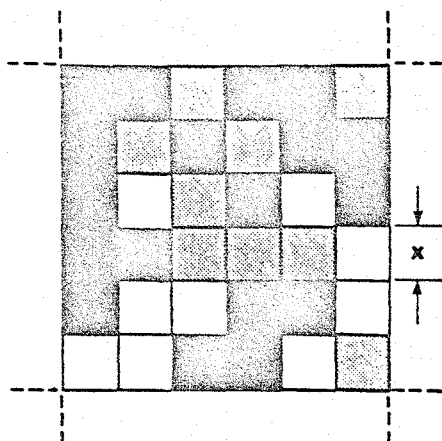
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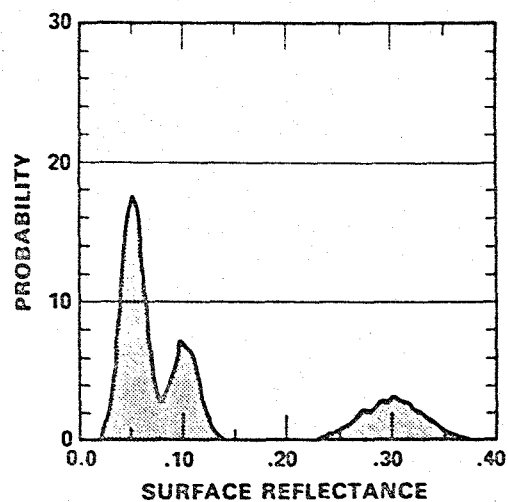
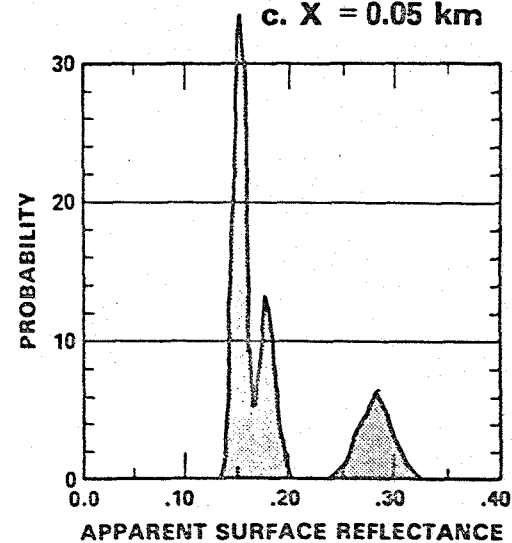
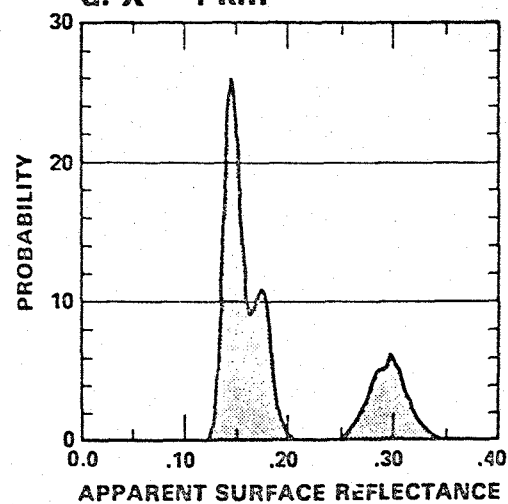
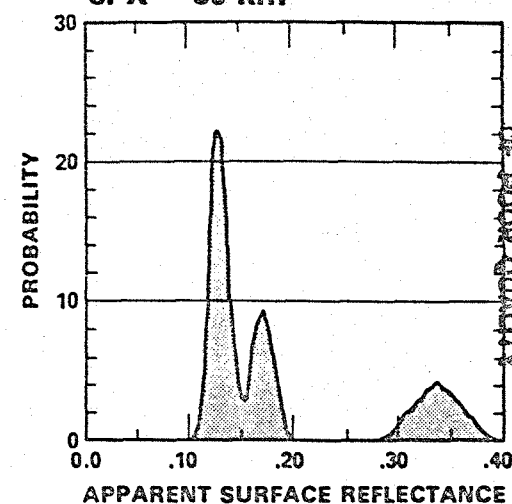




a. SURFACE FIELDS



b. NO ATMOSPHERE

c.  $X = 0.05$  kmd.  $X = 1$  kme.  $X = 80$  kmORIGINAL PAGE IS  
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## CHARACTERIZATION OF SURFACE REFLECTANCE VARIATION EFFECTS ON REMOTE SENSING

W. Pearce  
EG&G

### 0 GOALS AND OBJECTIVES

- o To model and characterize the effects of scattering phenomena impacting remote sensing in the visible:

- Aerosol profile variations
- Aerosol size distribution variations
- Viewing angle variation
- Bidirectional reflectance function variation
- Horizontal aerosol inhomogeneity (clouds)

- o Atmospheric effects algorithms

- Development
- Sensitivity studies

### 0 FIRST YEAR OBJECTIVES

- o Tool building

- Revision of simulation codes to suit new operational environment [ CTRANS, ARTRAN, Mie ]
- Validation
- Micro-to-mainframe communications
- Interactive graphics
- FFT (on micro)
- Linear filtering
- Cubic spline interpolation, differentiation and integration

- o Aerosol vertical profile variation effects

- Test noise suppression techniques
- Boundary effect
- MTF
- Line spread function

- \* From boundary intensities
- \* From inverse Fourier transform of MTF

- o Viewing angle effects

- Baseline Lambertian ground reflectance

SEE D75-22015

0 TECHNICAL PROGRESS AND ACCOMPLISHMENTS

o Software tools developed

- CTRANS Monte Carlo code restructured to improve efficiency
- ARTRAN created from CTRANS by removal of finite clouds capability
- ARTRAN validated by comparison with previous results
- Mie code revised to suit new computing environment
- Communications software modified to permit exchange of files between mainframe and micro-computers
- Software packages developed for microcomputer to permit interactive analysis of simulation results
  - \* Graphics
  - \* FFT
  - \* Linear filtering
  - \* Cubic spline interpolation, differentiation, and integration

o Aerosol vertical profile studies

- Moderate aerosol optical depth simulations shifting tropospheric aerosols into the stratosphere.
  - \* MTF
  - \* Boundary effect
  - \* Line spread function

o Viewing angle effects

- Simulations with Lambertian ground reflectance
- Moderate aerosol optical thickness
- Boundary effect

O RESULTS, FINDINGS

- o Moderate aerosol optical depth profile variations yield approximately linearly scaled variations in the line spread function compatible with single scattering model expectations.
- o Off-nadir viewing angle simulations qualitative only. Required: comparisons with nadir view cases with modified vertical optical depth.

O RELATIONSHIP WITH OTHER SRAEC INVESTIGATIONS

- o Complements radiative transfer models of Diner and of Gerstl
- o Can treat finite clouds and polarization effects
- o Can implement and test impact of reflectance models from Vanderbilt, Smith, Norman, and Strahler

O SECOND YEAR OBJECTIVES

- o Modeling
  - Aerosol size distribution effects on the atmospheric spread function
  - Bidirectional reflectance effects
    - \* homogeneous reflectance, inhomogeneous reflectivity
    - \* Inhomogeneous reflectance types
    - \* Polarization sensitivity
  - Finite clouds
    - \* Examine effects of clouds within and near field of view

- Parameterization

- \* Characterize inner and outer parts of the spread function
- \* Examine coupling with bidirectional ground reflectance

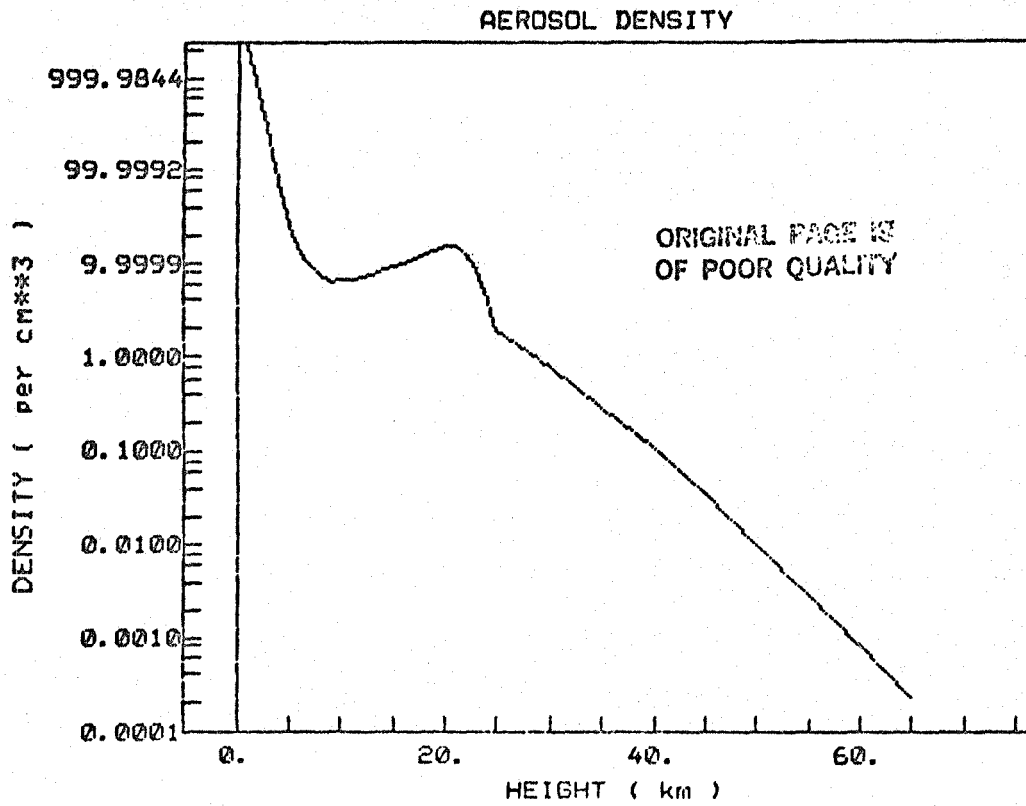
0 STUDY PARTICIPANTS

- o William A. Pearce
- o Y. Kaufman -- consulting

0 PUBLICATIONS

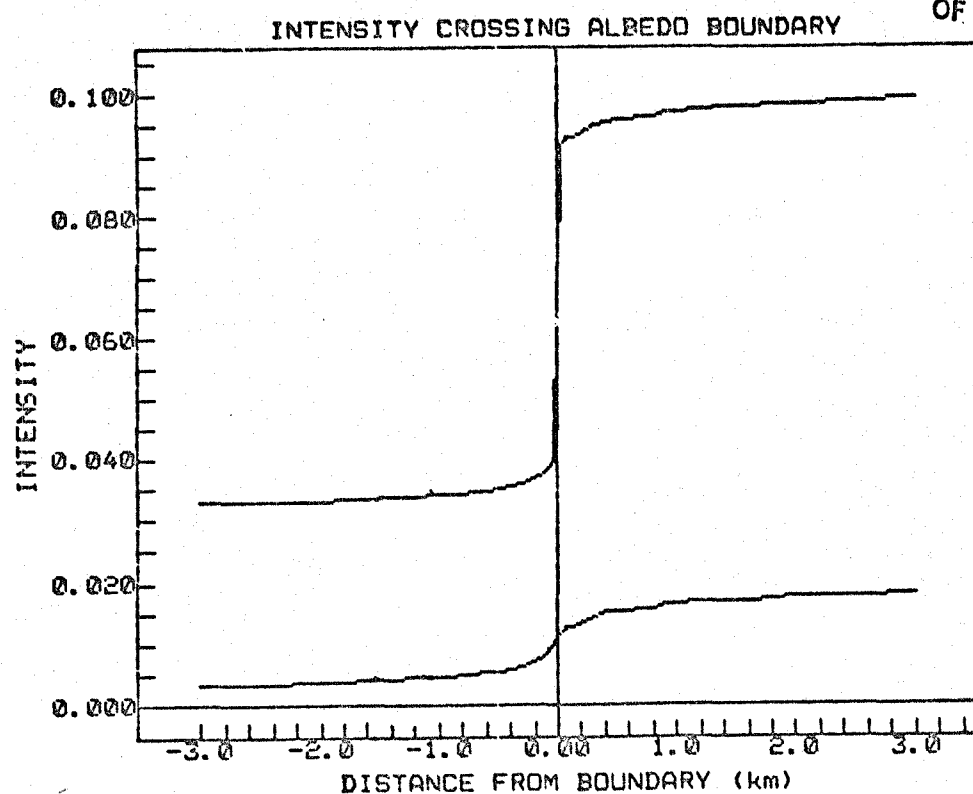
- o Planned: 1Q 84

- Code description, spread function variation with optical depth, aerosol profile, viewing angle, and aerosol size distribution



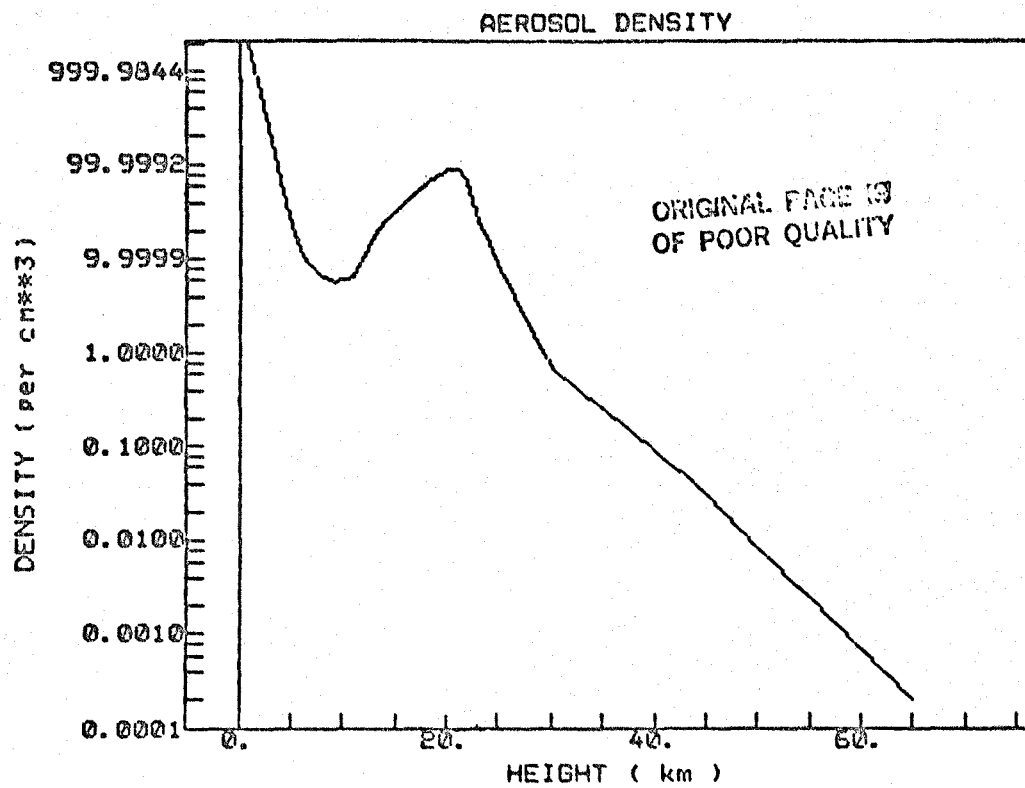
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ART001.CAP solar zenith angle = 40 deg.

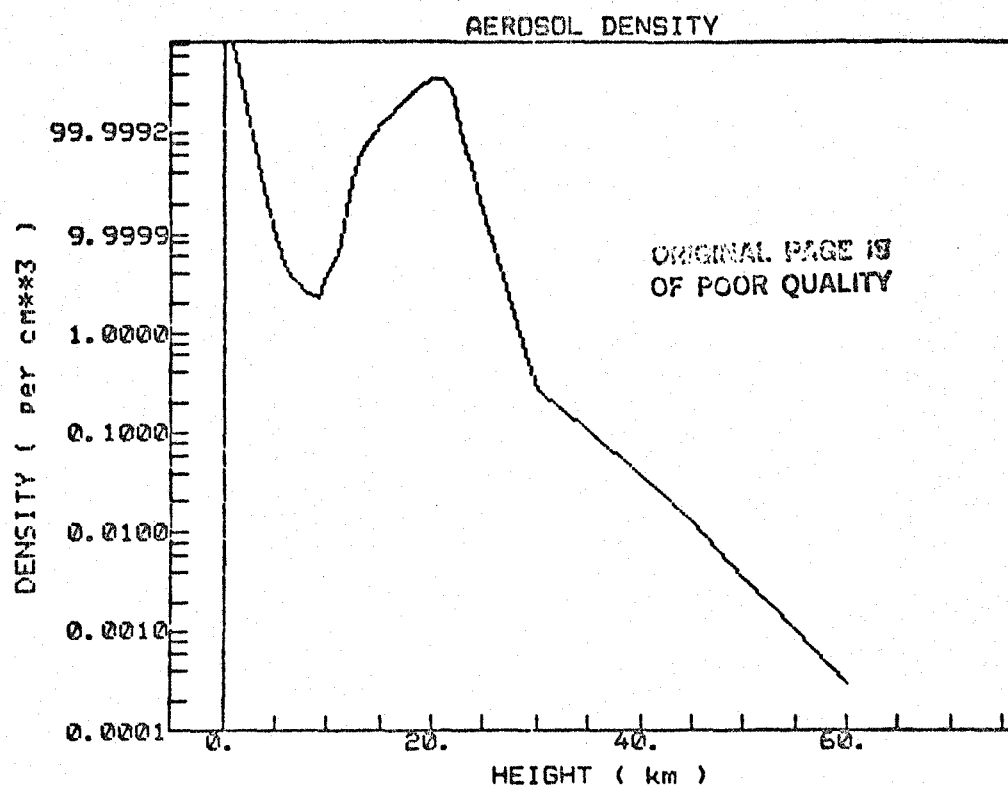




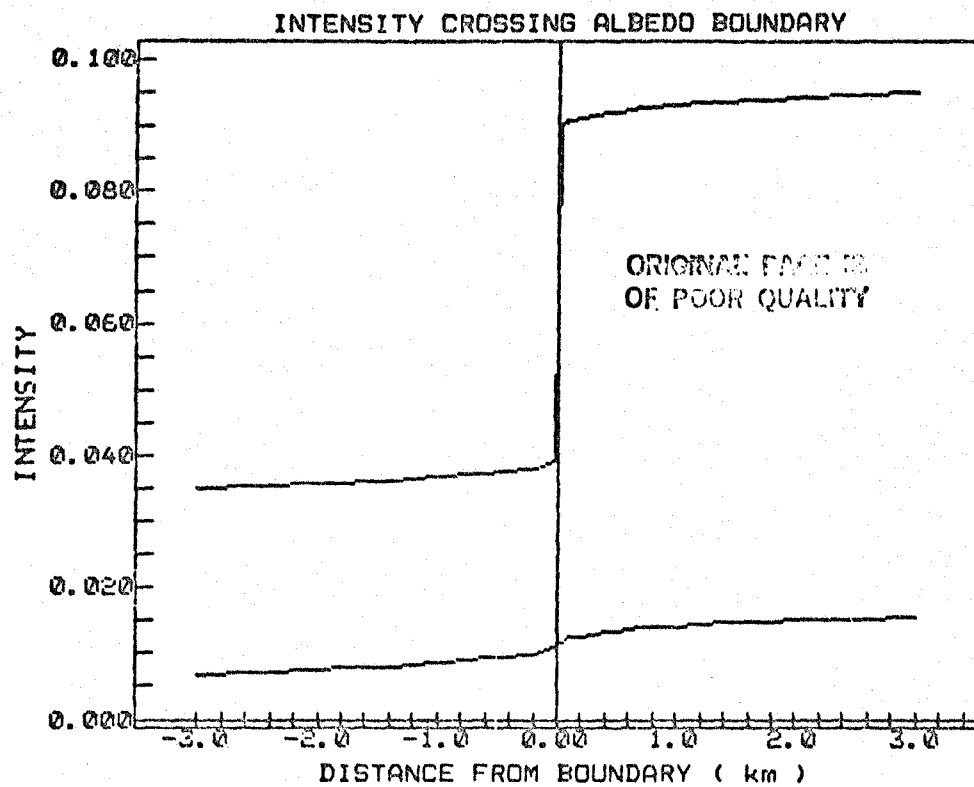
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ART003.CAP



ART003.CAP solar zenith angle = 40 deg.

MULTIDIMENSIONAL MODELING OF ATMOSPHERIC  
EFFECTS AND SURFACE HETEROGENEITIES ON REMOTE SENSING

S. Gerstl  
Los Alamos Natl. Lab.

BROAD GOALS AND OBJECTIVES:

IMPROVE UNDERSTANDING AND QUANTIFY EFFECTS OF

A) ATMOSPHERE AND ITS VARIABILITIES

- TURBIDITY/AEROSOLS
- CLOUDS/HAZE

B) SURFACE HETEROGENEITIES

- STRUCTURAL (CANOPY ARCHITECTURE)
- ANGULAR (BRDF BOUNDARY COND.)
- SPATIAL (ADJACENCY EFFECTS)

STUDY PARTICIPANTS:

(ALL AT LOS ALAMOS  
NATIONAL LABORATORY)

S. GERSTL (PI)

A. ZARDECKI (PH.D. COLLABORATOR)

C. SIMMER (POSTDOC STARTING JAN. 84)

SEE D1111 00/16

## FIRST YEAR OBJECTIVES

- ADAPT EXISTING RT CODES TO REMOTE SENSING APPLICATIONS
- IMPLEMENT BROAD ATMOSPHERIC DATA BASE
- VALIDATE CODES AND DATA
- DEFINE AND VERIFY A COUPLED ATMOSPHERE/CANOPY MODEL
- QUANTIFY EFFECTS OF CANOPY (BIOPHYSICAL) PARAMETERS
- ADD GENERAL BRDF SURFACE BOUNDARY CONDITIONS

## SECOND YEAR OBJECTIVES

- ESTABLISH MULTI-LAYER MODELS FOR PARAMETRIC STUDIES
- PERFORM SENSITIVITY STUDIES
- QUANTIFY EFFECTS OF ATMOSPHERIC TURBIDITY AND SURFACE BRDF
- EVALUATE EFFECTS OF SEMI-TRANSPARENT CLOUDS AND HAZE

## PUBLICATIONS

- 2 PAPERS OF FIRST 1½ YR. RESULTS ARE IN PREPARATION

## TECHNICAL PROGRESS AND ACCOMPLISHMENTS

- ACHIEVED ALL FIRST-YEAR OBJECTIVES
- DEMONSTRATED APPLICABILITY OF DISCRETE-ORDINATES FINITE-ELEMENT CODES TO ANALYZE EFFECTS OF
  - ATMOSPHERIC RAYLEIGH AND MIE SCATTERING
  - ANISOTROPIC LEAF SCATTERING
  - NON-LAMBERTIAN AND SPECULAR GROUND REFLECTANCE
- VERIFIED AND VALIDATED COUPLED ATMOSPHERE/CANOPY MODEL AGAINST FIELD MEASUREMENTS
- EXPANDED CAPABILITIES OF RT-CODES TO TREAT GENERAL BRDF BOUNDARY CONDITIONS
- CONCEPT OF KAUTH-THOMAS GREENNESS TRANSFORM CONFIRMED WITH OUR COUPLED ATMO./CANOPY MODEL
- NEW PHYSICAL INTERPRETATION SUGGESTED FOR KAUTH-THOMAS BRIGHTNESS TRANSFORM AS A MEASURE FOR  $\tau_{\text{ATM}}$  OR  $V_0$  OVER VEGETATIVE SURFACES

## RESULTS/SCIENTIFIC FINDINGS

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- 1) ATMOSPHERIC EFFECTS (AEROSOLS AND MOLECULAR SCATTERING) PLAY  
MAJOR ROLE IN VISIBLE, MINOR IN NEAR-IR:

FOR  $V_0 = 50$  TO  $5 \text{ km}$ :

$$\Delta I_{\text{REFL.}} \approx \begin{cases} 100 \text{ TO } 200\% \text{ IN VIS. (MSS A + B)} \\ 5 \text{ TO } 10\% \text{ IN NIR (MSS C + D)} \end{cases}$$

MSS - GREENNESS IS CONSTANT ( $\pm 1\%$ )

MSS - BRIGHTNESS  $B \approx c \cdot \tau_{\text{ATM.}}$  (MEASURE FOR ATM.)

- 2) INCLUSION OF ANISOTROPIC LEAF SCATTERING ( $g$  AND  $\tau$ )  
IMPROVES AGREEMENT WITH FIELD MEASUREMENTS:

FOR  $g = 0$  TO  $-0.5$ :

$$\Delta I_{\text{REFL.}}^{\text{VIS.}} \approx \begin{cases} 50\% \text{ ABOVE CANOPY} \\ 5\% \text{ ABOVE ATMOSPHERE} \end{cases}$$

$$\Delta I_{\text{REFL.}}^{\text{NIR}} \approx 5\% \text{ ABOVE CANOPY AND ATM.}$$



RESULTS/SCIENTIFIC FINDINGS

(CONTINUED)

- 3) NON-LAMBERTIAN AND SPECULAR SURFACE REFLECTANCE (BRDF) AFFECTS  
NADIR SATELLITE MEASUREMENTS ONLY INSIGNIFICANTLY:

- WITH CANOPY:  $\Delta I_{\text{REFL.}} \ll 5\% \text{ ABOVE ATM.}$   
(LAI = 1.5)
- WITHOUT CANOPY:  $\Delta I_{\text{REFL.}} \approx \begin{cases} 5\% \text{ IN VISIBLE} \\ 5-15\% \text{ IN NIR} \end{cases}$   
( $V_0 = 23\text{km}$ )

- 4) FOR OFF-NADIR VIEW DIRECTIONS NON-LAMBERTIAN BRDF OF SURFACE AND  
SPECULAR REFLECTION COMPONENT MAKE SIGNIFICANT DIFFERENCE!

## SIGNIFICANCE OF RESULTS

### A) TO SCENE IDENTIFICATION FROM LANDSAT MSS DATA:

- ATMOSPHERIC EFFECTS DOMINATE SIGNAL IN VISIBLE CHANNELS (MSS A + B), BUT
- MSS GREENNESS IS UNAFFECTED BY ATMOSPHERIC TURBIDITY.
- NADIR LANDSAT MEASUREMENTS ARE INSENSITIVE TO SURFACE BRDF.

### B) TO FUTURE ATMOSPHERIC CORRECTION ALGORITHMS:

- MSS BRIGHTNESS MAY BE USED TO ESTIMATE ATM. TURBIDITY ( $\tau_{\text{ATM}}$ , OR  $V_0$ ) OVER VEGETATIVE SURFACES

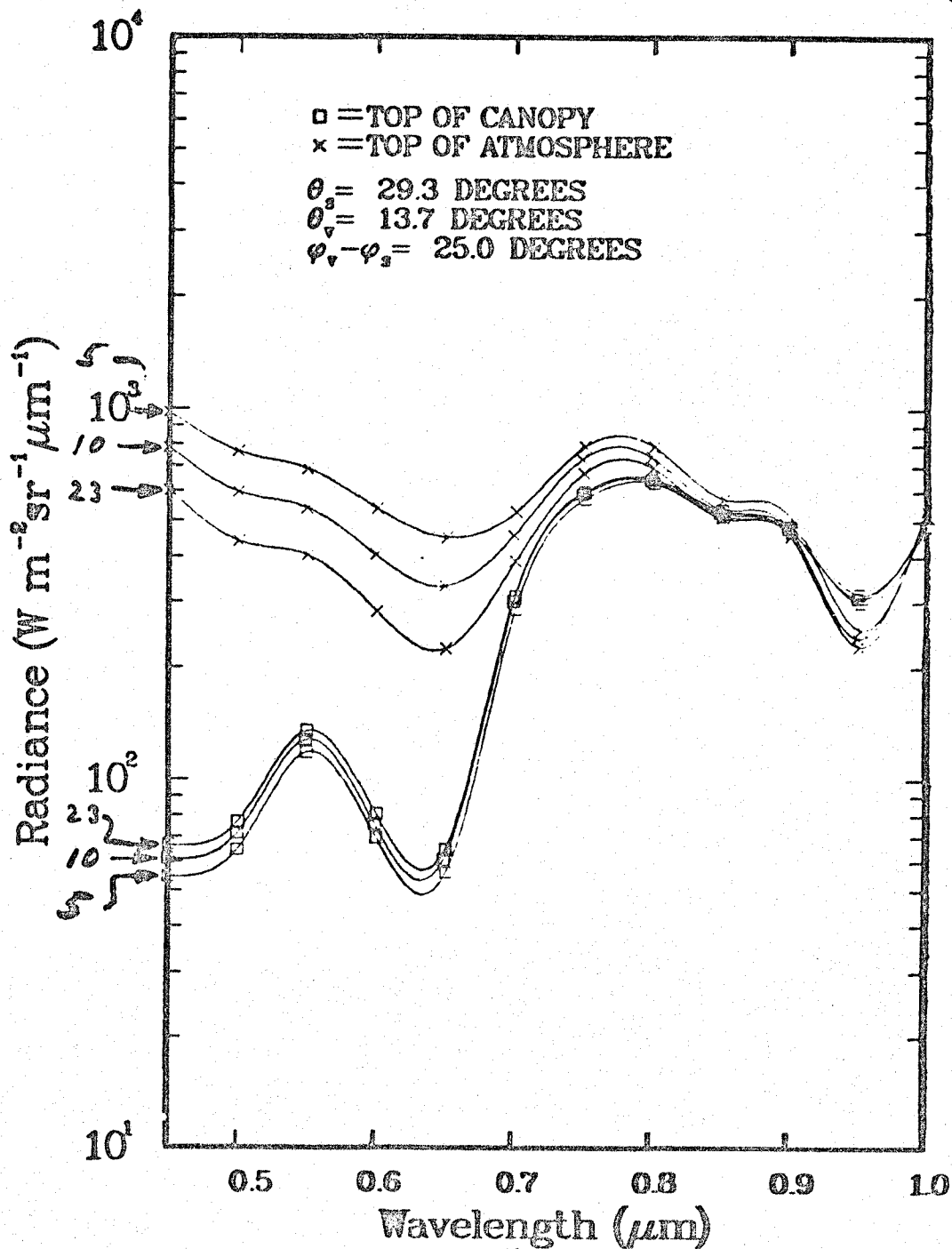
### C) TO CANOPY REFLECTANCE MODELING:

- ANISOTROPIC LEAF SCATTERING IS SIGNIFICANT TO EXPLAIN GROUND TRUTH CANOPY REFLECTANCE MEASUREMENTS,
- BUT NEGLIGIBLE EFFECT ON SATELLITE MEASUREMENTS.

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# VARY ATMOSPHERE

ATMOSPHERIC MODEL = 19 228511  $\rightarrow V_o = 23 \text{ km}$   
 $\angle AI = 1.5$   $V_o = 10 \text{ km}$   
CANOPY = 0.50 BRDF = 1.00 0.00 0.20  $V_o = 5 \text{ km}$



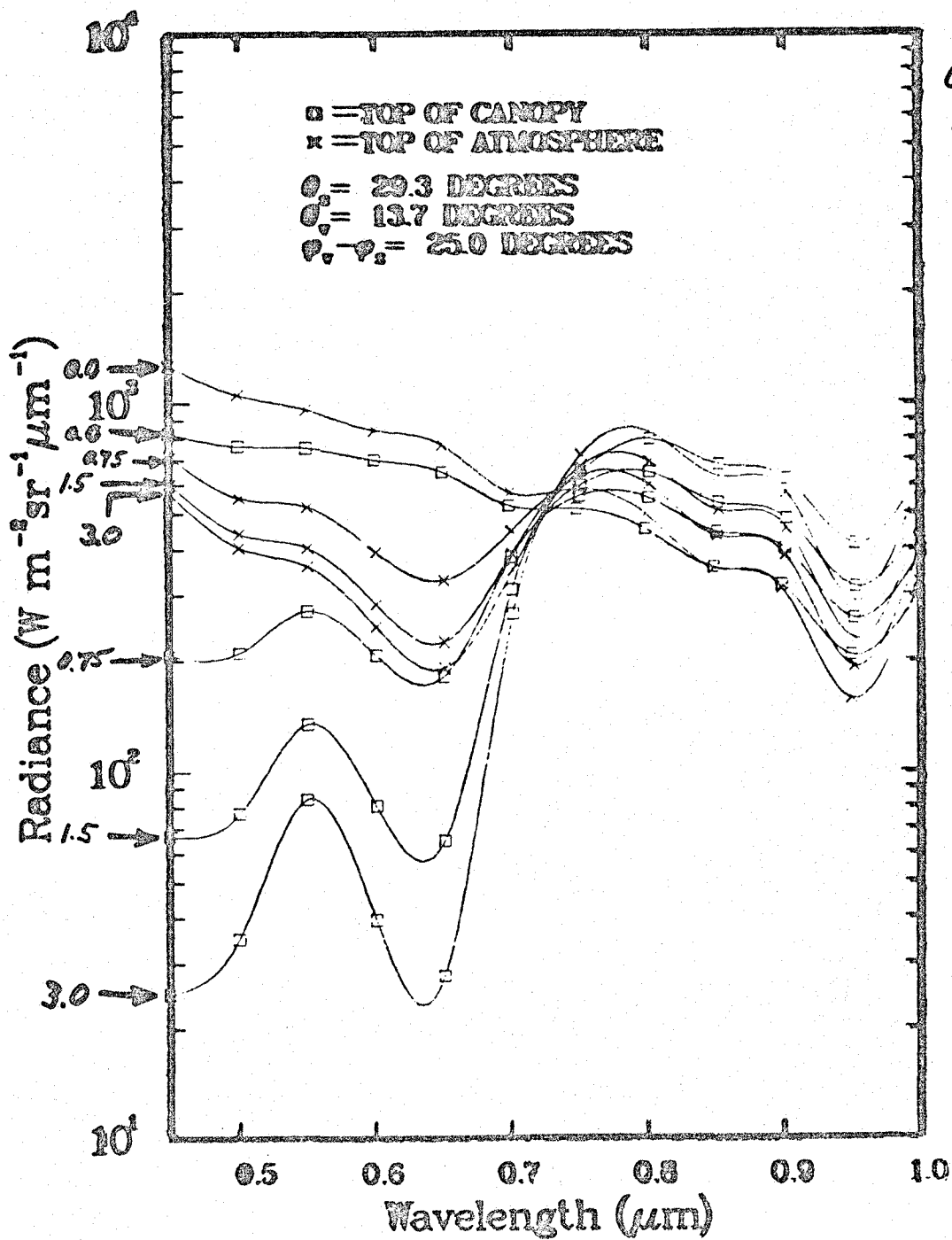
# VARY CANOPY

ATMOSPHERIC MODEL = 10 220311

$V_0 = 23 \text{ km}$

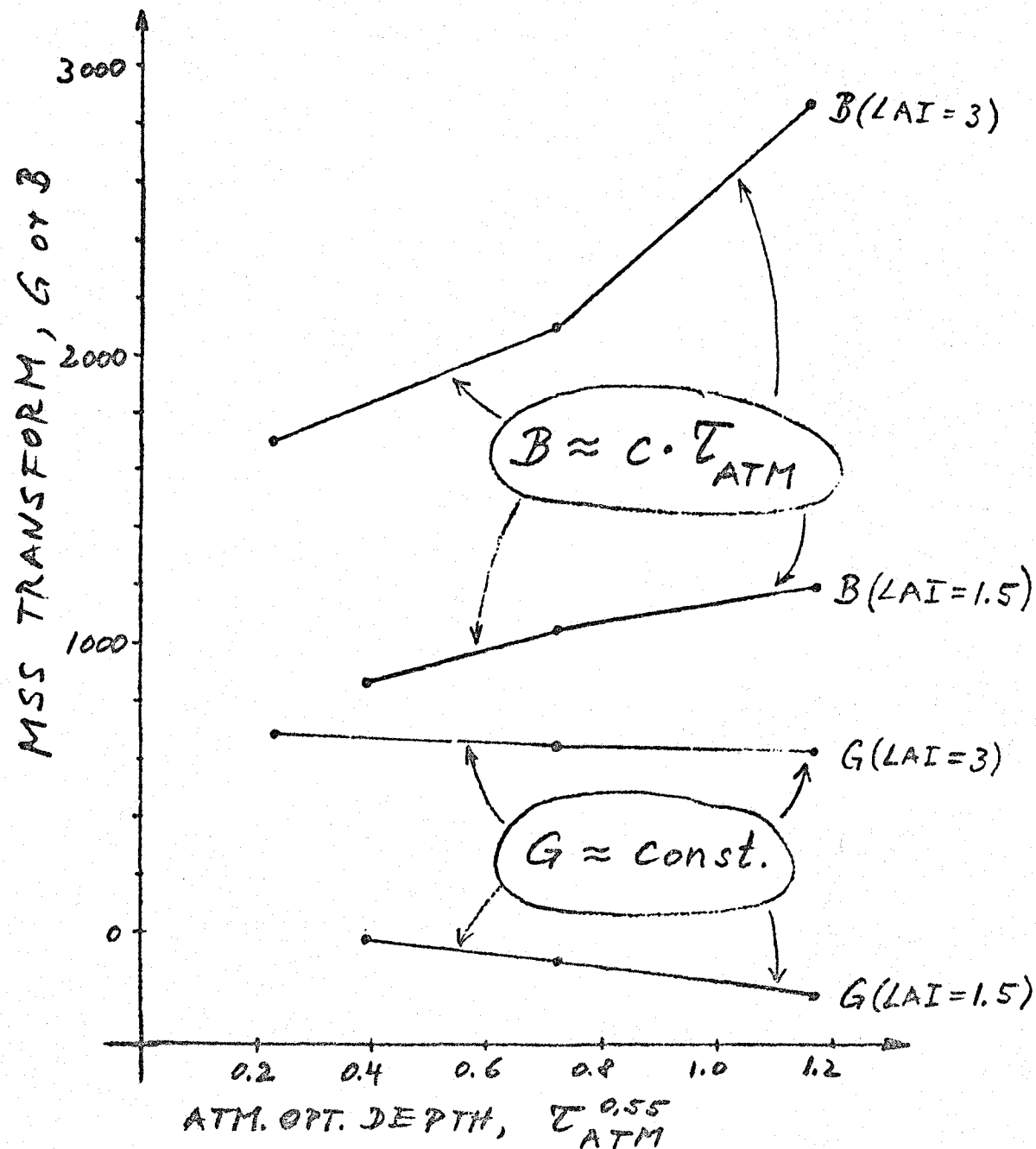
CANOPY = 0.00 BRDF = 1.00 0.00 0.20

LAI =  
3.0  
1.5  
0.75  
0.1



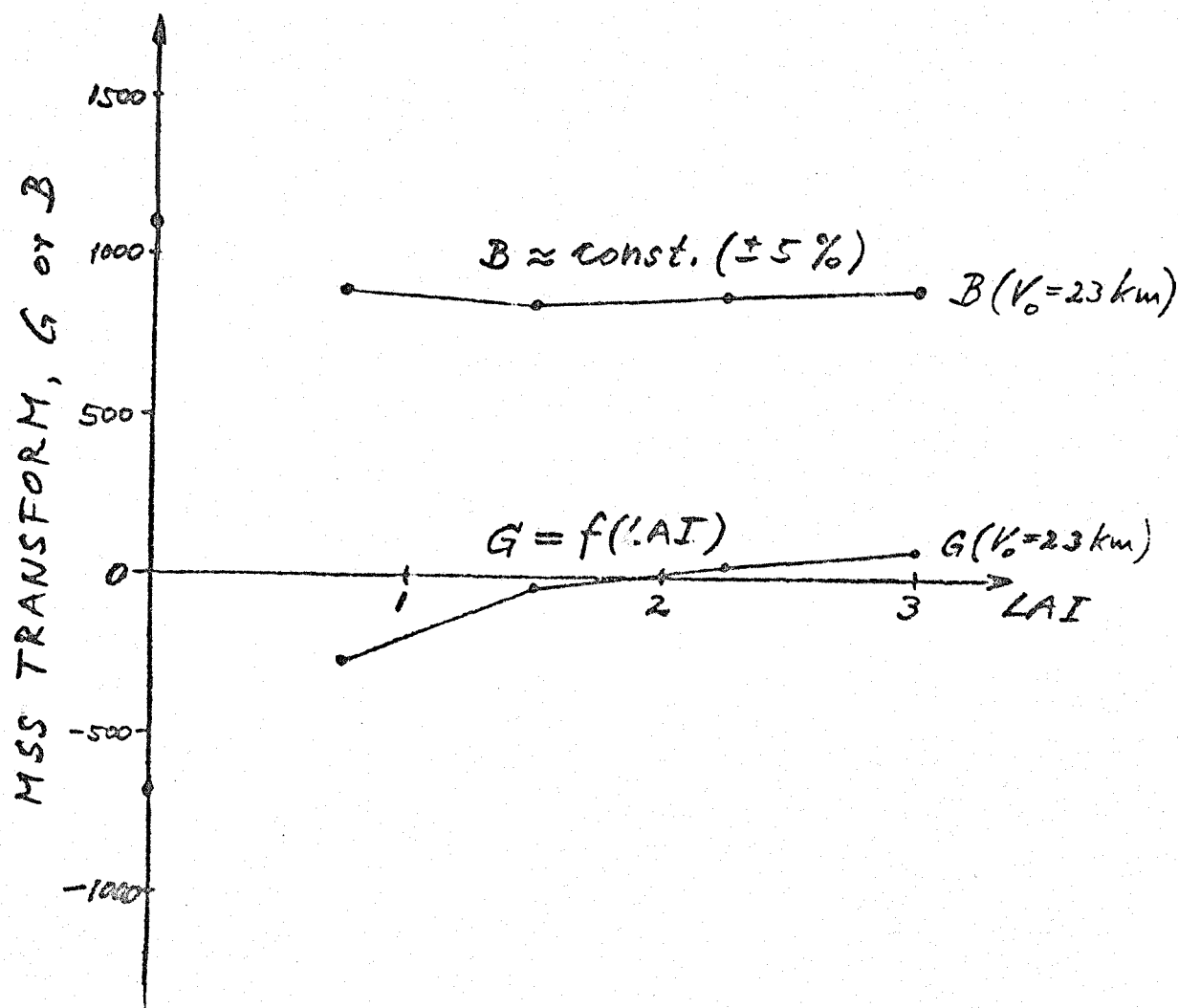
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MSS GREENNESS  $G$  } vs.  $\tau_{ATM}^{0.55}$   
MSS BRIGHTNESS  $B$  }



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MSS GREENNESS  $G$  } vs. LAI  
MSS BRIGHTNESS  $B$  }



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# VARY SOIL BRDF

ATMOSPHERIC MODEL = 19 216511

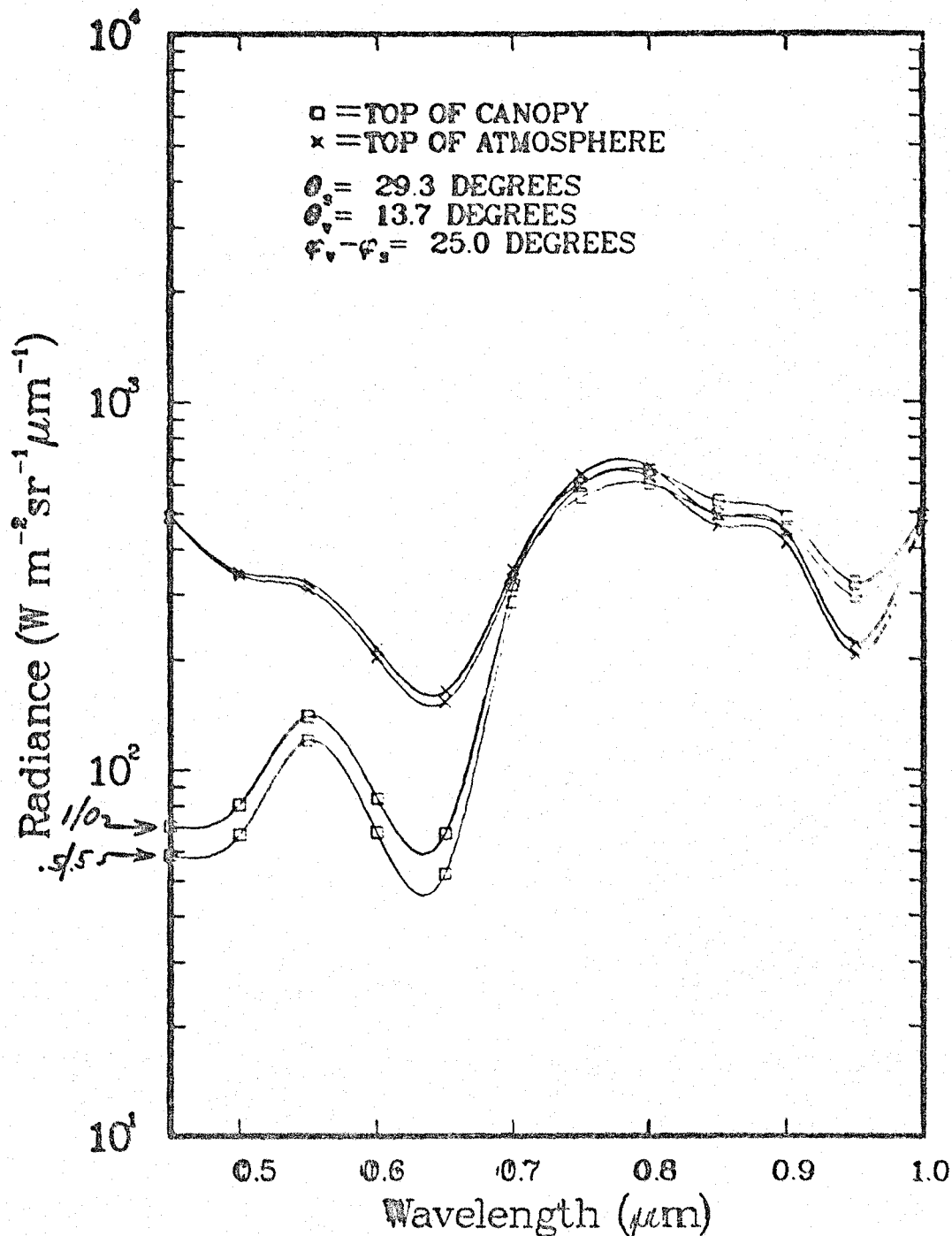
$\angle AI = 1.5$ ,  $V_0 = 50$  km

CANOPY = 0.50 BRDF = 0.00 0.00 0.20

$\angle AMB / \text{SPR}$

1/0

.5/.5



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VARY SURFACE BRDF  
ATMOSPHERIC MODEL = 10 220511

AS CANOPY,  $V_0 = 23 \text{ km}$

CANOPY = 0.00 BRDF = 0.00 0.00 0.20

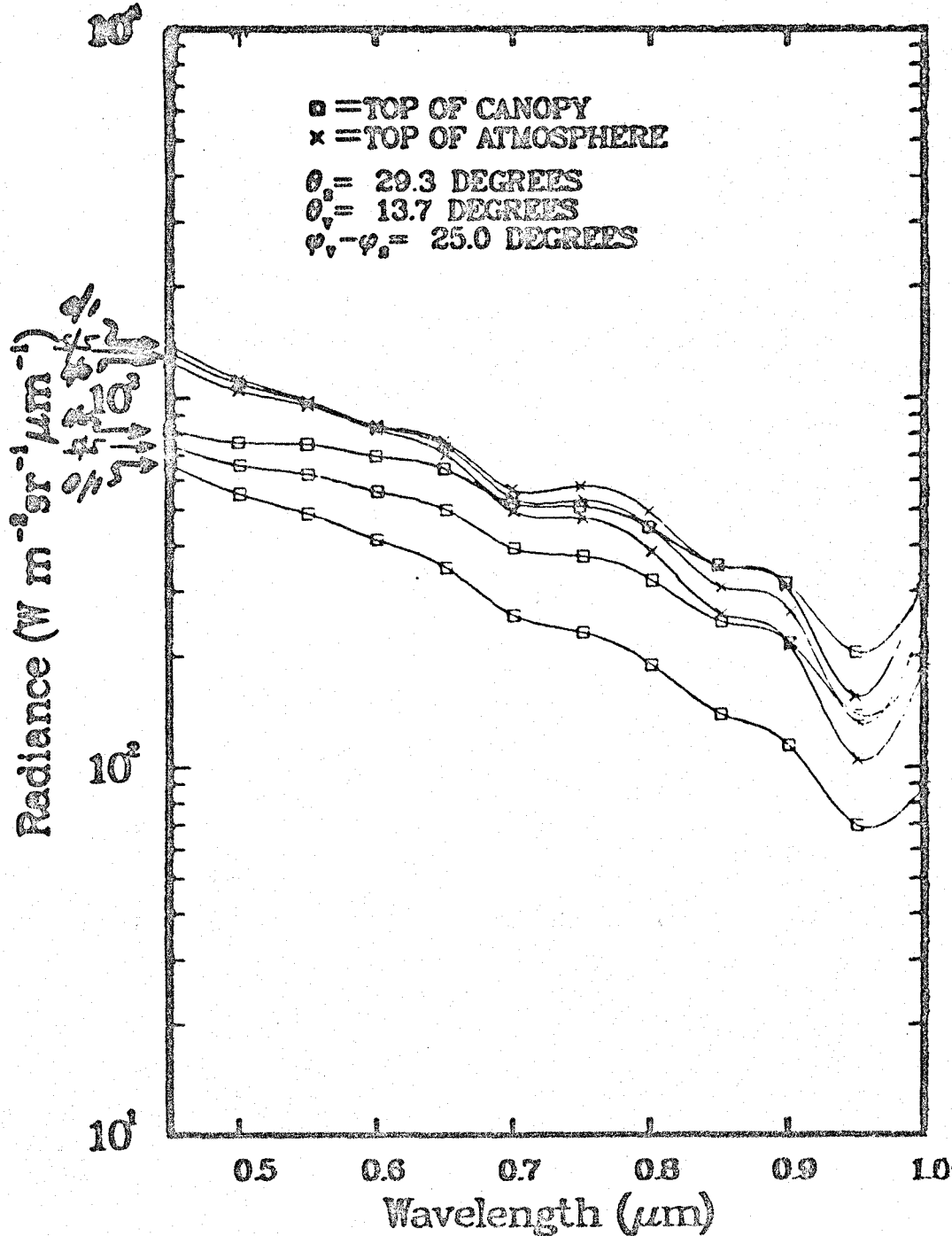
LAMB.

1/0

.5/.5

0/1

SPECULAR



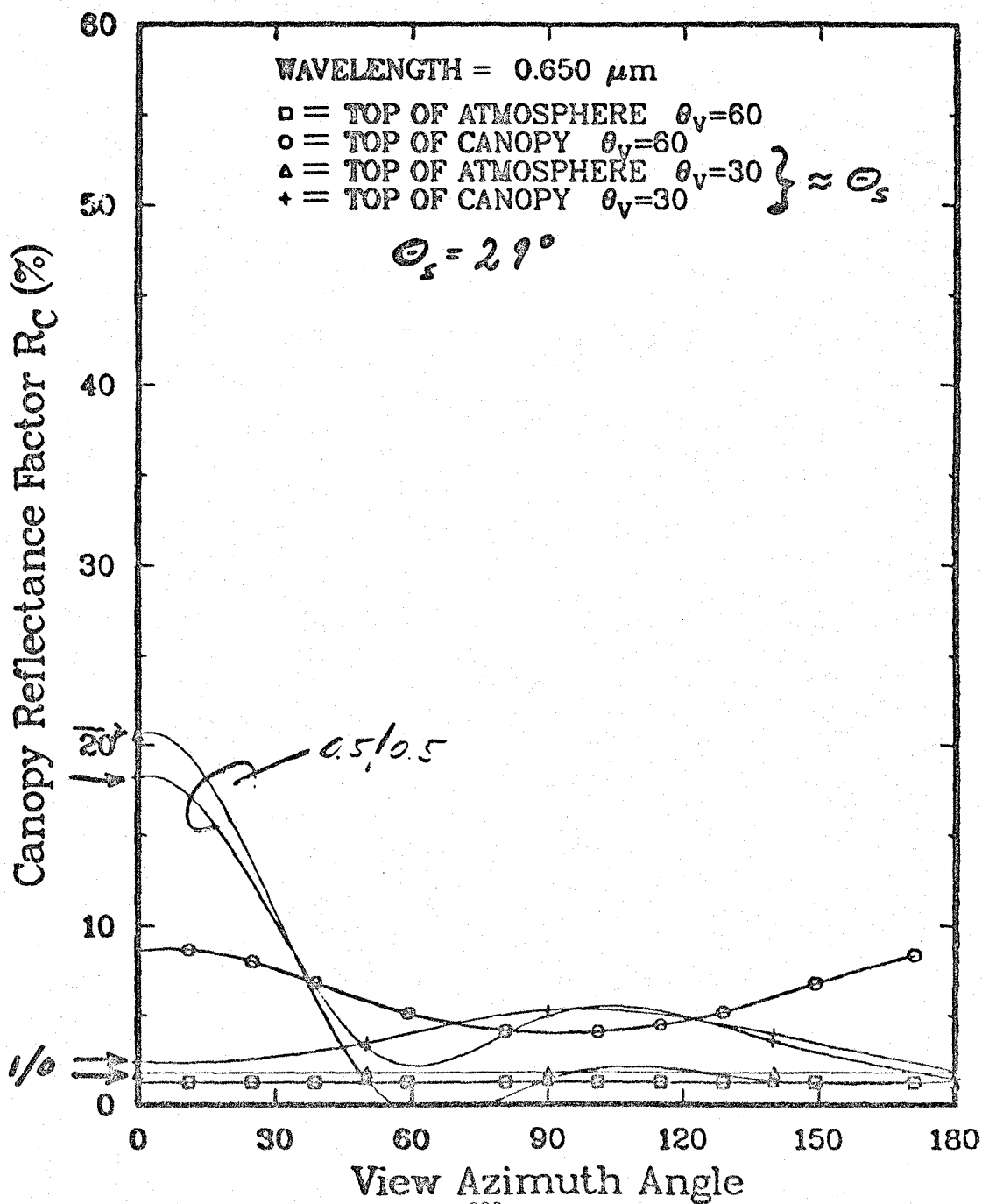


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VARY SOIL BRDF  
ATMOSPHERIC MODEL = 19 216511  
 $V_0 = 50 \text{ km}$

CANOPY = 0.50 BRDF = 0.60 0.00 0.20 →

LAMB/SPEC  
1.0/0.0  
.5/.5

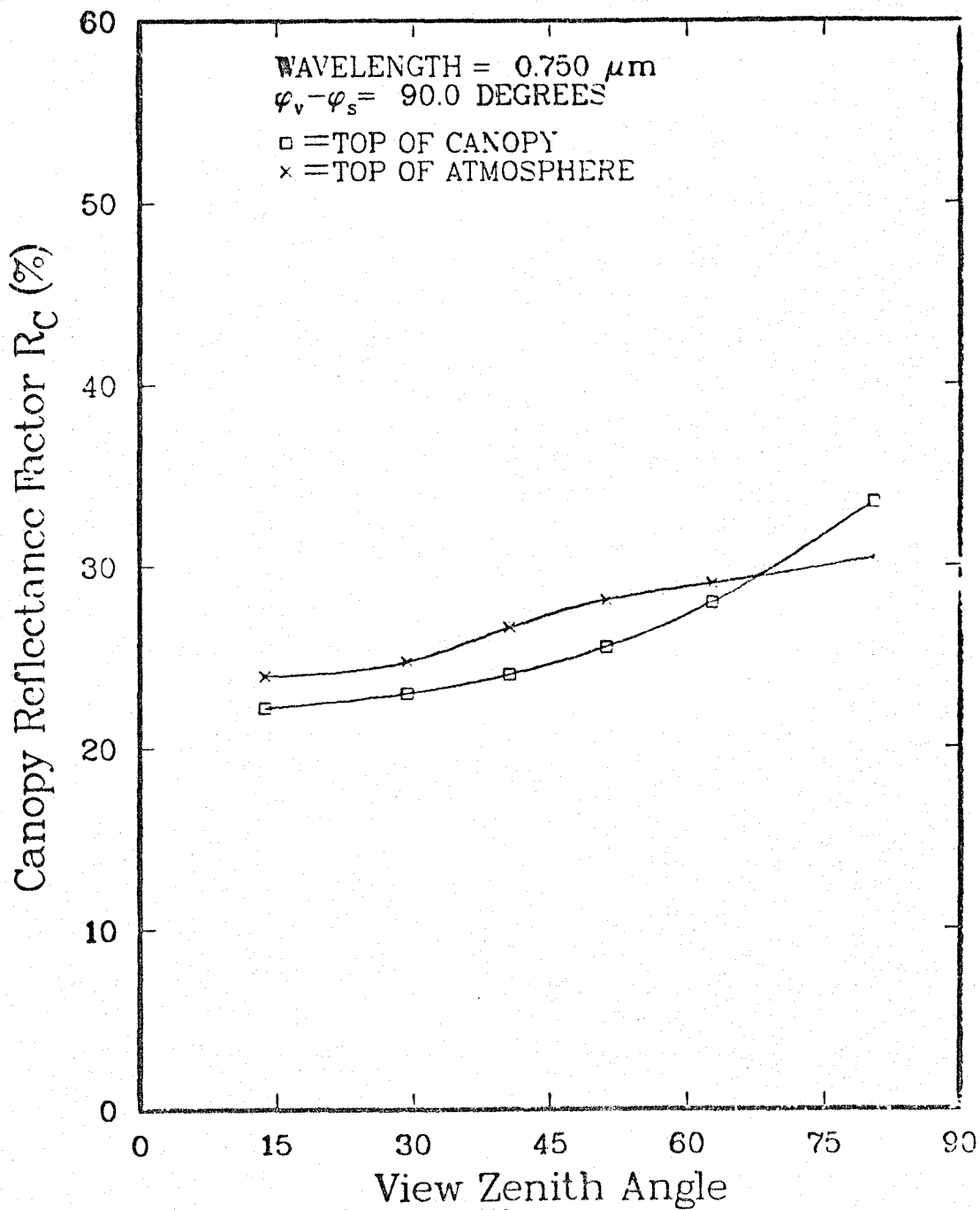


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ATMOSPHERIC MODEL = 19 216511

$V_0 = 50 \text{ km}$

CANOPY = 0.50 BRDF = 1.00 0.00 0:20



SEE PAGE 17

BIDIRECTIONAL SPECTRAL REFLECTANCE OF EARTH RESOURCES:  
INFLUENCE OF SCENE COMPLEXITY AND ATMOSPHERIC EFFECTS ON REMOTE SENSING

D. Diner  
NASA/JPL

OVERALL OBJECTIVES

INVESTIGATE UTILITY OF ANGULAR VARIATION OF REFLECTION SPECTRA IN IDENTIFICATION/  
DISCRIMINATION

STUDY EFFECTS OF CANOPY GEOMETRY AND SCATTERING ON REFLECTANCE PROPERTIES OF  
INDIVIDUAL LEAVES

DETERMINE EFFECTS OF ATMOSPHERIC SCATTERING ON ORBITAL MEASUREMENTS OF SURFACE  
SPECTRA AND BIDIRECTIONAL REFLECTANCES

DEVELOP ATMOSPHERIC CORRECTION/COMPENSATION ALGORITHMS

SPECIFIC OBJECTIVES

YEAR 1

SET-UP OF LABORATORY GONIOMETER FOR LEAF BIDIRECTIONAL REFLECTANCE  
MEASUREMENTS

DEVELOPMENT OF ATMOSPHERIC RADIATIVE TRANSFER ALGORITHM CAPABLE OF  
HANDLING NON-UNIFORM AND NON-LAMBERTIAN SURFACES

YEAR 2

ESTABLISHMENT OF LEAF GONIOMETRY CALIBRATION PROCEDURES AND PROCUREMENT  
OF SAMPLE SPECTRA

INVESTIGATION OF ATMOSPHERIC SCATTERING EFFECTS ON SURFACE REFLECTION  
USING 3-D FOURIER TRANSFORM CODE

ADDITION OF CAPABILITY TO HANDLE HORIZONTAL ATMOSPHERIC INHOMOGENEITIES  
IN RADIATIVE TRANSFER COMPUTATIONS

D. J. DINER

ACCOMPLISHMENTS AND RESULTS

3-D FOURIER TRANSFORM ATMOSPHERIC RADIATIVE TRANSFER CODE DEVELOPED -  
RESULTS COMPARE FAVORABLY TO MONTE CARLO

WIDTH OF ATMOSPHERIC POINT-SPREAD FUNCTION DEPENDS ON VIEWING ANGLE  
AND ATMOSPHERIC SCALE HEIGHT

DIFFERENT POWER SPECTRA OF DIRECT AND DIFFUSE RADIANCES IS BASIS FOR  
TECHNIQUE TO DETERMINE ATMOSPHERIC OPTICAL DEPTH

PRELIMINARY LEAF GONIOMETRY INDICATES SPECTRAL VARIABILITY WITH VIEW  
ANGLE.

D. J. DINER

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SIGNIFICANCE TO SRAFC PROGRAM

RESULTS TO DATE PRIMARILY IN ATMOSPHERIC STUDIES -

NEW RADIATIVE TRANSFER CODE HAS BROAD APPLICABILITY

MULTIPLE VIEW ANGLE OPTICAL DEPTH DETERMINATION TECHNIQUE -

RETRIEVES FUNDAMENTAL ATMOSPHERIC PROPERTY USEFUL FOR CORRECTING  
SURFACE MEASUREMENTS

LEAF GONIOMETRY WILL BE USEFUL TO CANOPY MODELLERS

POSSIBLE APPLICATION OF 3-D RADIATIVE TRANSFER ALGORITHMS TO COMPUTATION  
OF LIGHT SCATTERING IN PLANT CANOPIES

D. J. DINER

## PARTICIPANTS

DAVID J. DINER, JPL (PRINCIPAL INVESTIGATOR)

JOHN V. MARTONCHIK, JPL (Co - INVESTIGATOR)

WILLIAM D. SMYTHE, JPL/UCLA (Co - INVESTIGATOR)

CHARLES HESSOM, UCLA (GRADUATE STUDENT)

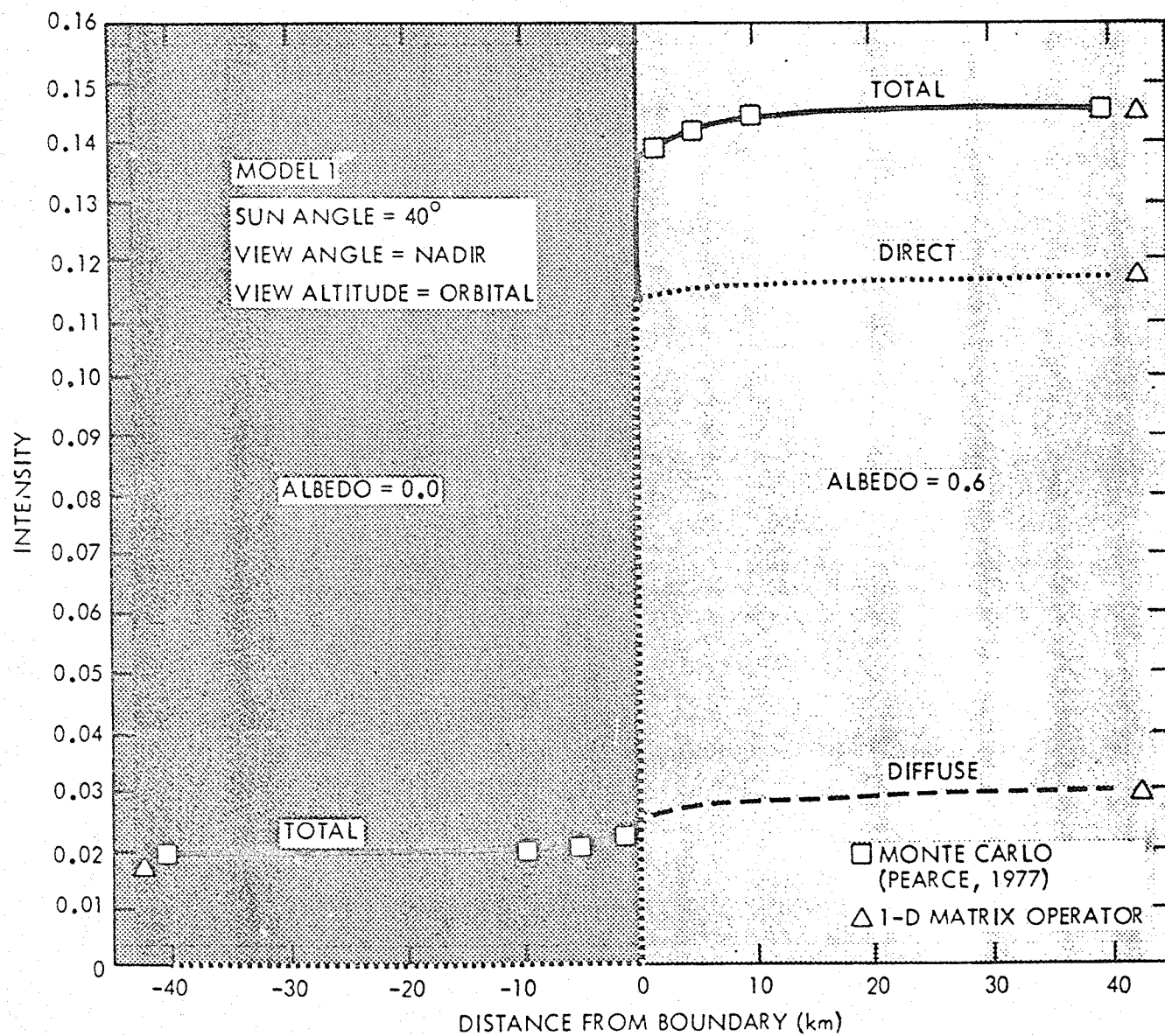
## PUBLICATIONS

ATMOSPHERIC TRANSFER OF RADIATION ABOVE AN INHOMOGENEOUS NON-LAMBERTIAN  
SURFACE. I. THEORY  
(TO APPEAR IN JQSRT)

ATMOSPHERIC TRANSFER OF RADIATION ABOVE AN INHOMOGENEOUS NON-LAMBERTIAN  
SURFACE. II. COMPUTATIONAL CONSIDERATIONS AND RESULTS.  
(SUBMITTED TO JQSRT)

THREE-DIMENSIONAL RADIATIVE TRANSFER USING A FOURIER TRANSFORM MATRIX  
OPERATOR METHOD.  
(IN PREPARATION)

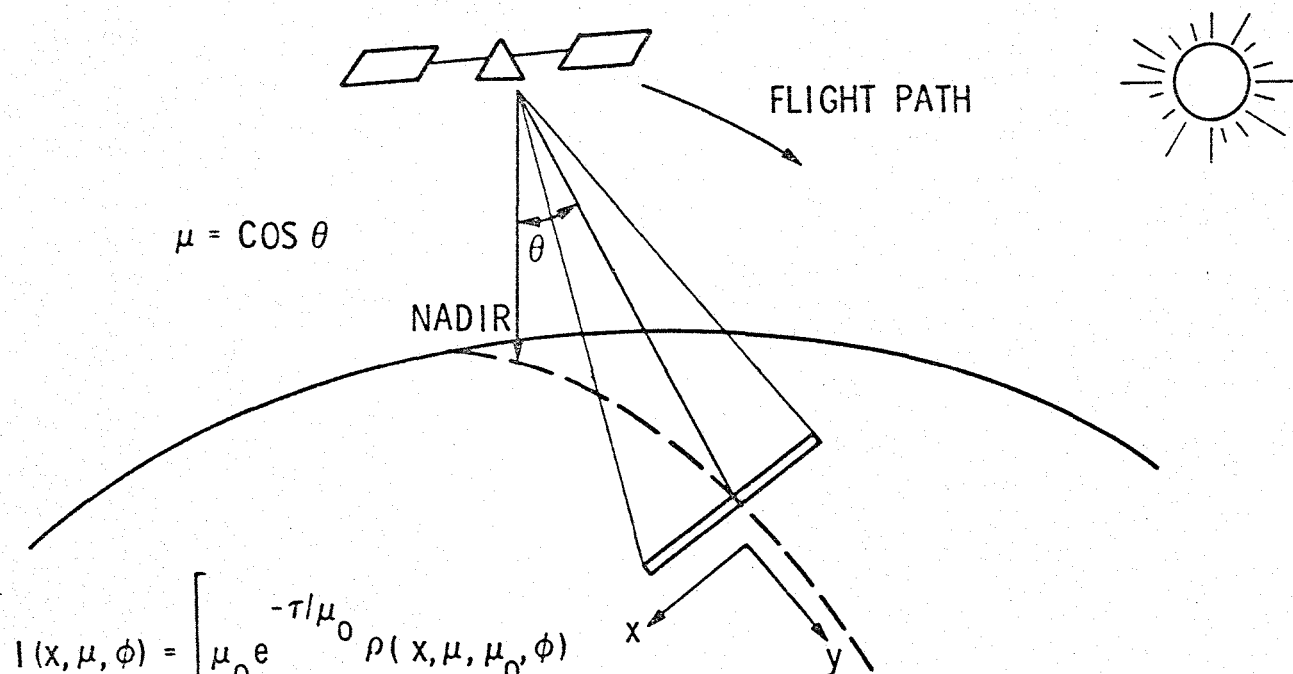
D. J. DINER







# OFF-NADIR PUSH-BROOM IMAGING THROUGH ATMOSPHERE



$$\mu = \cos \theta$$

$$I(x, \mu, \phi) = \left[ \mu_0 e^{-\tau/\mu_0} \rho(x, \mu, \mu_0, \phi) \right.$$

$$\left. + \frac{1}{\pi} \int_0^1 \int_0^{2\pi} I_d(x, \mu', \phi') \rho(x, \mu, \mu', \phi - \phi') \mu' d\mu' d\phi' \right] Fe^{-\tau/\mu} \text{ (DIRECT)}$$

$$+ D(x, \mu, \phi)$$

(DIFFUSE)

$$+ N(x)$$

(NOISE)

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OF POOR QUALITY



# DETERMINATION OF ATMOSPHERIC OPTICAL DEPTH

$$I(x, \mu, \phi) = F(x, \mu, \phi) e^{-\tau/\mu} + D(x, \mu, \phi) + N(x)$$

- COMPUTE POWER SPECTRUM VS. SPATIAL FREQUENCY  $s$
- SUM OVER FREQUENCY TO MINIMIZE UNCORRELATED CROSS TERMS
- RESTRICT TO HIGH SPATIAL FREQUENCIES SUCH THAT  $D_s \rightarrow 0$

$$M_s(\mu, \phi) = \sum_{s'=s}^{s_{MAX}} |\bar{I}_{s'}(\mu, \phi)|^2 - |\bar{N}_{s'}|^2 = e^{-2\tau/\mu} \sum_{s'=s}^{s_{MAX}} |\bar{F}_{s'}(\mu, \phi)|^2 + \text{CROSS TERMS}$$

$$= e^{-2\tau/\mu} G_s(\mu, \phi) + \dots$$

- OBTAIN MEASUREMENTS OF SAME SWATH AT 2 VIEW ANGLES:  $\mu_1 = \mu + \Delta\mu$  AND  $\mu_2 = \mu - \Delta\mu$
- TAKE RATIO AND LOGARITHM . FOR SMALL  $\Delta\mu$ :

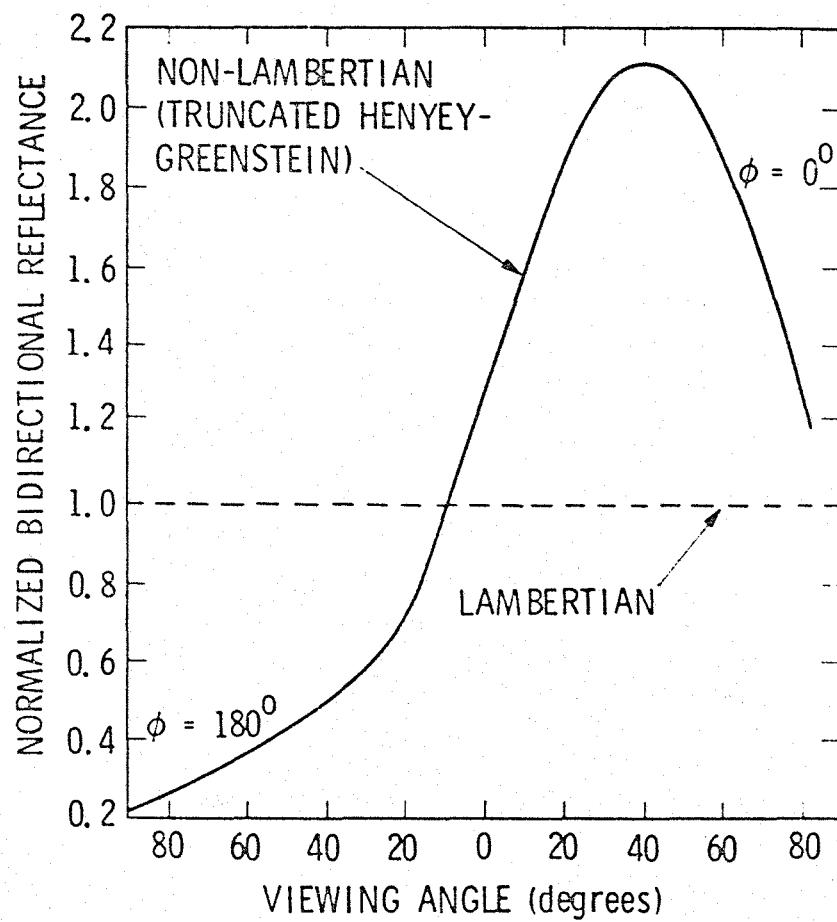
$$\tau_s(\mu, \phi) \sim \tau \cdot \frac{1}{2} \mu^2 \frac{\partial \ln G_s(\mu, \phi)}{\partial \mu} + \text{ADDITIONAL TERMS}$$

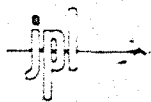
OPTICAL DEPTH

DEPEND ON CONTRIBUTION FROM  
DIFFUSE RADIATION AND NOISE

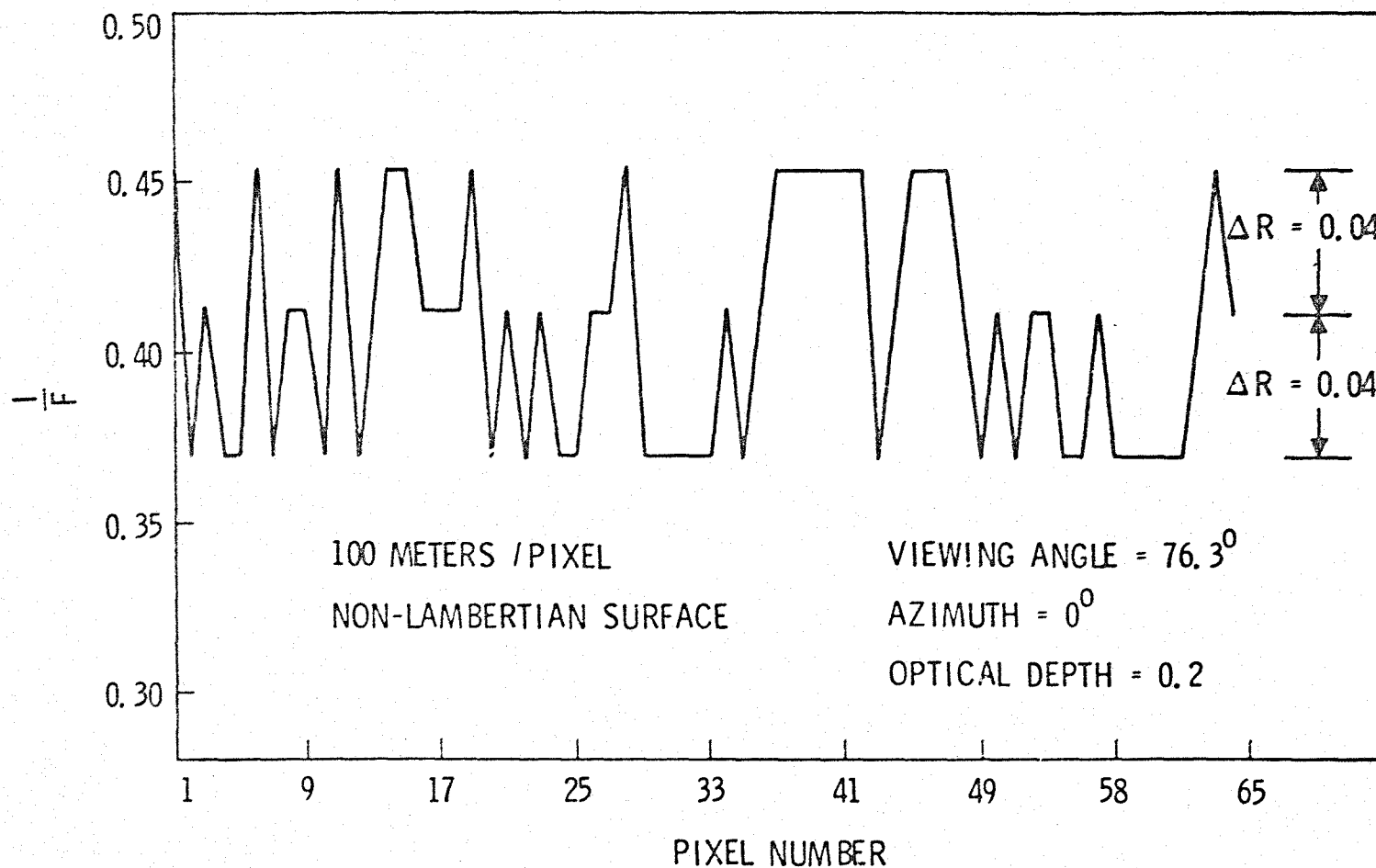
OBTAINED FROM  
MEASUREMENTS

DEPENDS ON SURFACE  
BIDIRECTIONAL REFLECTANCE DISTRIBUTION

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OF POOR QUALITY



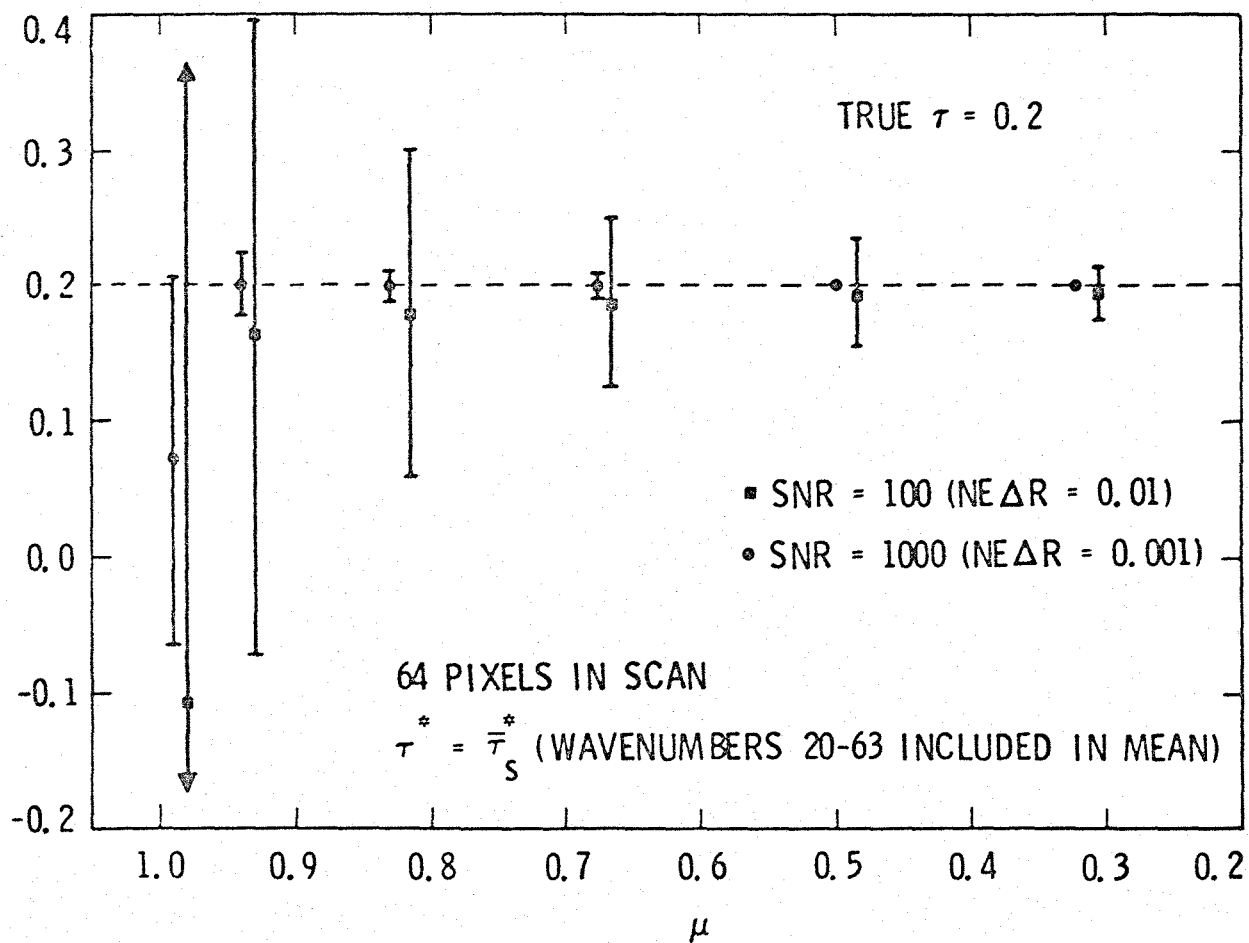
## RADIANCE VS. POSITION



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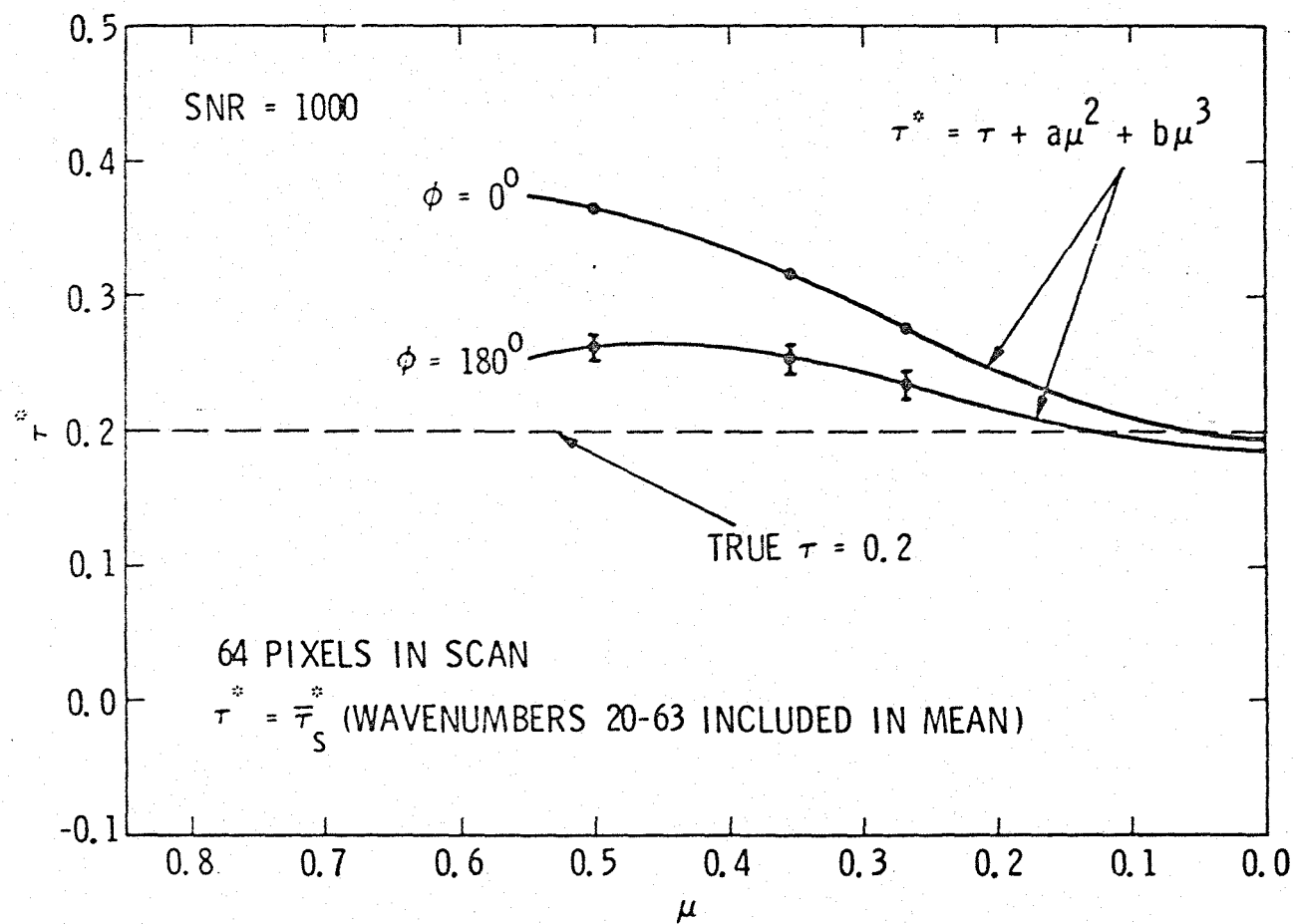
## LAMBERTIAN SURFACE



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## NONLAMBERTIAN SURFACE



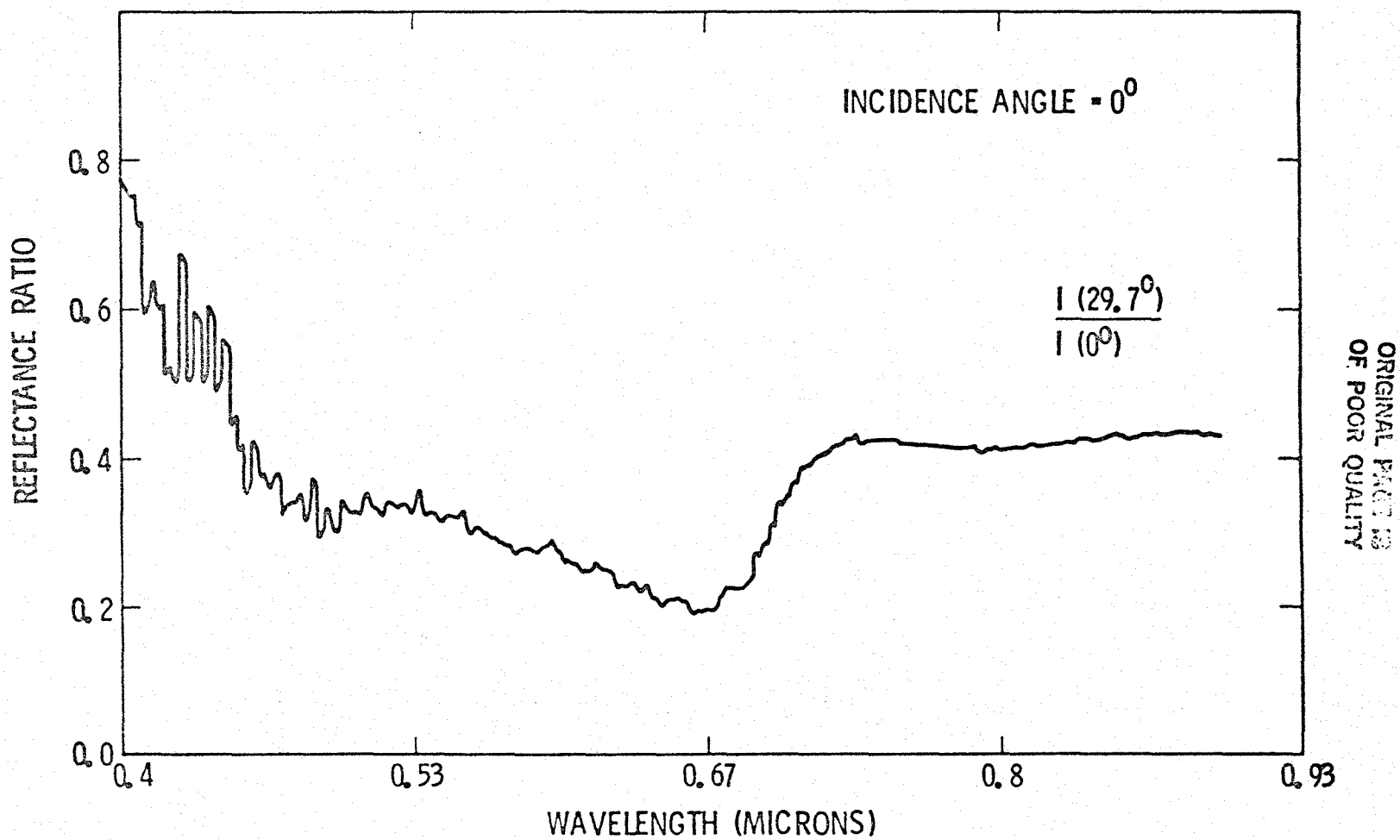
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## **JPL** REQUIREMENTS OF OBSERVATIONAL SYSTEM (PUSH-BROOM IMAGER)

- OFF-NADIR VIEWING (UP TO  $\sim 75^{\circ}$ )
- HIGH SPATIAL RESOLUTION (TENS OF METERS)
- HIGH SIGNAL-TO-NOISE RATIO ( $> 100$ )
- FORWARD AND AFT VIEWING DESIREABLE

JPL

# CAMELLIA LEAF





III.D. LIST OF PUBLICATIONS AND PRESENTATIONS - SRAEC PROJECT

### III.D. LIST OF PUBLICATIONS AND PRESENTATIONS - SRAEC PROJECT

#### Publication List

The following SRAEC project supported publications are organized according to: (1) published refereed journal articles, (2) journal articles "in press" (3) prepared journal manuscripts submitted/in review, (4) thesis or dissertation, (5) miscellaneous reports, and (6) symposium or conference presented papers or proceedings.

#### 1. Published Journal Articles

Chuang, S.L. and J.A. Kong, 1983, "Wave scattering and guidance by dielectric waveguides with periodic surfaces," Journal of the Optical Society of America, Vol. 73, No. 5.

Fung, A.K. and H.J. Eom, 1983, "Effects of a rough boundary surface on polarization of the scattered field from an inhomogeneous medium," IEEE Geoscience and Remote Sensing, (IGARSS '82), Vol. AP-21, No. 3, pp. 265-270.

Grant, L., V.C. Vanderbilt and C.S.T. Daughtry, 1983, "Measurements of specularly reflected radiation for individual leaves," Agronomy Abstracts 75:12.

Jin, Y.Q. and J.A. Kong, 1983, "Scattering and active remote sensing of atmospheric precipitation," Applied Optics, Vol. 22, 2535-2545.

Karam, M. and A.K. Fung, 1983, "Scattering from randomly oriented circular discs with application to vegetation," Radio Science, Vol. 18, No. 4, pp. 557-565.

Kaufman, Y.J. and R.S. Fraser, 1983, "Different atmospheric effects in remote sensing of uniform and non-uniform surfaces," Adv. Space Res., 2, 147-155.

Kimes, D.S. and J.A. Kirchner, 1982, "Irradiance Measurement Errors Due to the Assumption of a Lambertian Reference Panel", Remote Sensing of Environment, 12:141-149.

Kimes, D.S. and J.A. Kirchner, 1982, "Radiative Transfer Model for Heterogeneous 3-D Scenes," Applied Optics, 21(22):4119-4129.

Kimes, D.S. and J.A. Kirchner and J.E. McMurtrey III, 1982, "Variation of Directional Reflectance Factors with Structural Changes of a Developing Alfalfa Canopy," Applied Optics, 22:3766-3774.

Kimes, D.S. and J.A. Kirchner, 1983, "Directional Radiometric Measurements of Row-Crop Temperatures," Int. J. Remote Sensing, 4(2):299-311.

Kimes, D.S., 1983, "Remote Sensing of Row Crop Structure and Component Temperatures Using Directional Radiometric Temperatures and Inversion Techniques," Remote Sensing of Environment, 13:33-55.

Kimes, D.S. and J.A. Kirchner, 1983, "Diurnal Variations of Vegetation Canopy Structure," Int. J. Remote Sensing, 4(2):257-271.

Kimes, D.S., 1983, "Dynamics of Directional Reflectance Factor Distributions for Vegetation Canopies," Applied Optics, 22:1364-1372.

Kimes, D.S., J.A. Kirchner and W.W. Newcomb, 1983, "Spectral Radiance Errors in Remote Sensing Ground Studies Due to Near By Objects," Applied Optics, 22:8-10.

Lang, R.H. and J.S. Sidhu, 1983, "Electromagnetic backscattering from a layer of vegetation: A discrete approach," IEEE Transaction on Geoscience and Remote Sensing, Vol. GE-21, No. 1, p. 62.

LeVine, D.M., R. Meneghini, R.H. Lang and S.S. Seker, 1983, "Scattering from arbitrarily oriented disks in the physical optics regime," J. Opt. Soc. Amer., Vol. 73, p. 1255.

Norman, J.M. and J.M. Welles, 1983, "Radiative transfer in an array of canopies," Agron. J., 75:481-488.

Paris, J.F., 1983, "Radar backscattering properties of corn and soybeans at frequencies of corn and soybeans at frequencies of 1.6, 4.75 and 13.3 GHz," IEEE Trans. Geosci. and Remote Sensing, GE-21(3), 392-400.

Tsang, L. and J.A. Kong, 1983, "Scattering of electromagnetic waves from a half space of densely distributed dielectric scatterers," Radio Science, Vol. 18, No. 6, 1260-1272.

## 2. Journal Articles "In Press"

Badhwar, G.D., "Automatic classification of corn and soybean using Landsat data: Part I: Near-harvest crop proportion estimation, Remote Sensing of Environment.

Badhwar, G.D., "Automatic classification of corn and soybean using Landsat data: Part II: Early-season crop proportion estimation, Remote Sensing of Environment.

Fung, A.K. and H.J. Eom, "A scatter model for vegetation up to ku-band," Remote Sensing of Environment.

Fung, A.K. and H.J. Eom, "Scattering from a random layer with application to snow, vegetation and sea ice," IEEE Proceedings - Special Issue of Radiowave Propagation.

Henderson, K.E. and G.D. Badhwar, "An initial model for estimating development stages from spectral data," Remote Sensing of Environment.

Jin, Y.Q. and J.A. Kong, "Strong fluctuation theory for electromagnetic wave scattering by a layer of random discrete scatterers," Journal of Applied Physics.

Kaufman, Y.J. and R.S. Fraser, "The Atmospheric effect on classification of finite fields," Remote Sensing of Environment.

Kimes, D.S., B.N. Holben, C.J. Tucker and W.W. Newcomb, "Optimal Directional View Angles for Remote Sensing Missions," Int. J. Remote Sensing.

Kimes, D.S., W.W. Newcomb, J.B. Schutt, P.J. Pinter, Jr., and R.D. Jackson, "Directional reflectance factor distributions of a cotton row crops," Int. J. of Remote Sensing.

Kong, J.A., S. Lin and S.L. Chuang, "Thermal microwave emission of periodic surface," IEEE Transactions on Geoscience and Remote Sensing.

Lee, J.K. and J.A. Kong, "Dyadic Green's functions for layered anisotropic medium" Electromagnetics.

Shin, R.T. and J.A. Kong, "Scattering of electromagnetic waves from a randomly perturbed quasi-periodic surface," Journal of Applied Physics.

Tsang, L., J.A. Kong and R.T. Shin, "Radiative transfer theory for active remote sensing of a layer of non-spherical particles," Radio Science.

Ulab, F.T. and R.P. Jedlicka, "Microwave dielectric Properties of plant materials," IEEE Transactions of Geoscience and Remote Sensing.

Vanderbilt, V.C., L. Grant, L.L. Biehl and B.F. Robinson, "Specular, diffuse and polarized light scattered by two wheat canopies," Applied Optics.

### 3. Submitted Journal Manuscripts

Badhwar, G.D., "Use of Landsat-derived profile features for Spring small grains classification," International Journal of Remote Sensing.

Diner, D.J. and J.V. Martonchik, "Atmospheric transfer of radiation above an inhomogeneous non-lambertian reflective ground. I. Theory," submitted to Journal of Quantitative Spectroscopy and Radiative Transfer.

Diner, D.J. and J.V. Martonchik, "Atmospheric transfer of radiation above an inhomogeneous non-lambertian reflective ground. II. Computational considerations and results," submitted to J. Quant. Spectr. Rad. Transf.

Kaufman, Y.J., "Atmospheric effect on spatial resolution of surface imagery," submitted for publication in Applied Optics.

Kimes, D.S., "Modeling the Directional Reflectance from Complete Homogeneous Vegetation Canopies with Various Leaf Orientation Distribution," Journal of the Optical Society of America, in review.

Kimes, D.S., W.W. Newcomb, C.J. Tucker, I.S. Zonneveld, W. Van Wijngaarden, G.F. Epema, and J. DeLeeun, "Directional Reflectance Factor Distributions for Cover Types of Northern Africa in NOAA 7/8 AVHRR Bands 1 and 2," Remote Sensing of Environment, in review.

Randolph, M.H., "A RTE phase function description of vegetation canopies," submitted to IEEE Trans. Geosc. and Rem. Sens.

Vanderbilt, V.C. "Measuring plant canopy structure," submitted to Photogrammetric Engineering and Remote Sensing.

#### 4. Thesis and Dissertation

Franklin, J., 1983, "An empirical study of the spatial pattern of coniferous trees," M.A. Thesis, Univ. of California, Santa Barbara.

Randolph, M.H., 1983, "A radiative transfer equation/phase function approach to vegetation canopy reflectance modeling," Ph.D. Thesis, Colorado State University, Ft. Collins, CO.

#### 5. Miscellaneous Reports

Alexander, L and G.D. Badhwar, 1983, "Sail canopy model Fortran software," LEMSCO-19867.

Helmer, D. J. Krantz, M. Tompkins, and G.D. Badhwar, 1983, "User guide for the extraction of Landsat spectral and agronomic data," AgRISTARS Document JSC-18598.

Helmer, D., J. Krantz, M. Kinsler, M. Tompkins and G.D. Badhwar, 1983, "Composition and assembly of a spectral and agronomic data base for 1980 spring small grain segments," AgRISTARS Document.

Helmer, D., J. Krantz, M. Kinsler, M. Tompkins and G.D. Badhwar, 1983, "Argentina spectral data base," AgRISTARS Document.

Shin, R.T. and J.A. Kong, 1983, "Emissivity of a two-layer random medium with anisotropic correlation function," Technical Report No. EWT-RS-41-8303, MIT.

#### 6. Symposia and Conference

Allen, C.T. and F.T. Ulaby, 1984, "Modeling the polarization dependence of the attenuation in vegetation canopies," to be presented at the 1984 International Geoscience and Remote Sensing Symposium (IGARSS '84), Strasbourg, France.

Fraser, R.S. and Y.J. Kaufman, 1983, "The relative importance of aerosol scattering and absorption in remote sensing," Fifth Conference on Atmosphere Radiation, Baltimore, MD.

Jedlicka, R.P. and F.T. Ulaby, "Measurements of the Microwave Dielectric and Attenuation Properties of Plants," National Radio Science Meeting (URSI Commission F), University of Colorado, Boulder, CO.

Jin, Y.Q. and J.A. Kong, 1983, "Mie scattering of electromagnetic waves by precipitation," Optical Society of America Topical Meeting on Optical Techniques for Remote Probing of the Atmosphere, Lake Tahoe, Nevada.

Karam, M. and A.K. Fung, 1983, "Scattering from randomly oriented scatterers of arbitrary shape in the low-frequency limit with application to vegetation," Digest of IGARSS'83, IEEE 1983 International Geoscience and Remote Sensing Symposium.

- Kaufman, Y.J., T.W. Brakke and E. Eloranta, 1983, "Field experiment to measure the radiative characteristics of a hazy atmosphere," Fifth Conference on Atm. Rad., Baltimore, MD.
- Kong, J.A., 1982, "Theoretical models for microwave remote sensing of vegetation and soil moisture," AgRISTARS Symposium, Houston, TX.
- Kong, J.A., S.L. Lin, S.L. Chuang, and R.T. Shin, 1983, "Remote sensing of soil moisture and vegetation," URSI Symposium, Boulder, CO.
- Lang, R. and D.M. LeVine, 1983, "Backscattering from a vegetation layer--a multiple component model," National Radio Sci. Meeting, Boulder, CO.
- Lang, R.H., A. Schneider and S. Seker, 1983, "Mean wave propagation in a trunk forest," National Radio Science Meeting, Houston, TX.
- Lang, R.H., 1984, "Backscattering from a vegetation layer: Coherent and incoherent models," Microwave Signatures in Remote Sensing, URSI Symposium, Toulouse, France.
- Paris, J.F., 1983, "Effects of vegetation canopy structure on microwave backscatter," National Radio Sci. Meeting, Boulder, CO.
- Paris, J.R., 1983, "On the use of polarized radar measurements for vegetation studies," International Geosci. and Remote Sensing Symp., San Francisco, CA, FP5-5.
- Shin, R.T. and J.A. Kong, 1983, "Thermal microwave emission from a scattering medium with rough surfaces," URSI Symposium, Boulder, CO.
- Teillet, P.M., R. Brown, J.A. Smith and G. Federejeus, 1983, "Reflectance model studies," at the CCRS International Colloq. on Spectral Sign. in Remote Sens., Bordeaux, France.
- Tsang, L. and J.A. Kong, 1983, "Scattering of electromagnetic waves from a half-space of densely distributed dielectric scatterers," IEEE/APS Symposium and URSI Meeting, San Francisco, CA.
- Tsang, L. and J.A. Kong, 1983, "Theory of microwave remote sensing of dense medium," IEEE/GRS Symposium and URSI Meeting, San Francisco, CA.
- Ulaby, F.T., R.P. Jedlicka and C.T. Allen, 1984, "Measuring and modeling the dielectric and attenuation properties of vegetation," to be presented at the International Union of Radio Science Meeting (URSI Commission F), Toulouse, France.
- Ulaby, F.T., 1983, "Microwave properties of vegetation canopies: An overview," International Colloquium on spectral signatures of objectives in remote sensing, Bordeaux, France.
- Vanderbilt, V.C. and L. Grant, 1983, "Light polarization measurements: A method to determine the specular and diffuse light-scattering properties of both leaves and plant canopies, conference paper presented to the International Colloquium on Spectral Signatures of Objects in Remote Sensing, Bordeaux, France.
- Vanderbilt, V.C., L. Grant, L.L. Biehl and B.F. Robinson, 1983, "Specular and diffuse reflectance of two wheat canopies measured at many view angles," International Union of Radio Science.

APPENDIX

APPENDIX A  
SRAEC PROJECT  
LIST OF PRINCIPAL INVESTIGATORS

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(317) 494-6346 or 6305



## APPENDIX C

### AGENDA

#### Second Annual Workshop of the NASA Fundamental Research Scene Radiation and Atmospheric Effects Characterization Project CSU/Ft. Collins, Colorado

##### Monday, January 9

Welcome  
NASA Perspectives  
Terms and Measurements in the Optical Regime  
    Dr. Don Deering--Canopy & Soil Measurements  
    Dr. John Norman--Leaf Measurements and Interpretations  
        Through Modeling  
Terms and Measurements in the Radar/Microwave Regime  
    Dr. Jack Paris  
Terms and Concepts in the Atmospheric Sciences  
    Dr. Siegfried Gerstl

##### Tuesday, January 10

Optical Terrain Reflectance Modeling  
    Dr. James Smith  
Radar/Microwave Modeling  
    Dr. Adrian Fung  
Atmospheric Measurements  
    Dr. Y. Kaufman  
Model Inversion  
    Dr. N. Goel  
Principal Investigator Reports  
    A. Fung  
    F. Ulaby  
    R. K. Moore (Reza Zoughi)  
    R. Lang  
    R. Fraser  
    Y. Kaufman  
MPRIA Presentations  
    R. Heydorn  
    A. Strahler  
    L. Schumaker

##### Wednesday, January 11

Principal Investigator Reports  
    D. Diner  
    S. Gerstl  
    A. Strahler  
    G. Badhwar  
    D. Kimes  
    J. Smith  
    J. Norman  
    J. Kong  
    J. Paris  
    V. Vanderbilt

5. For optical wavelengths, soil reflectance enhances reflectance from vegetated surfaces and has a significant effect for leaf area index less than 3. Soil reflectance decreases as soil surface irregularities increase. At greater look angles, soil irregularities cause less variation in soil reflectance than they do at near-nadir look angles. A smooth soil surface approximates a Lambertian surface.
6. For optical wavelengths, the bidirectional reflectance distribution function for any given plant varies as a function of the diurnal movements of the plant in response to external stimuli.
7. Specular reflection is a significant factor in the bidirectional reflectance distribution function of leaves. By quantifying and subtracting the specular component, the remaining diffuse component in the reflectance distribution correlates significantly with leaf moisture content for infrared measurements and chlorophyll viability for measurements in the red region.
8. Atmospheric effects on target reflectance include, by nature, the adjacency effect, i.e., reflectance from the ground outside the immediate view scattered by the atmosphere into the field-of-view of the sensor. Recent results indicate the adjacency effect decreases the separability of image field classes when one dimension of a field approaches the height of the atmospheric aerosol layer above the target.
9. The use of off-nadir viewing is better for estimating atmospheric optical depth from reflectance.
10. Results show a correlation between brightness and atmospheric optical depth over full canopy coverage.

Some conclusions and recommendations evolved from the workshop discussions which are relevant to our future program direction. Briefly, these include:

- (1) The measurement of plant water content provides a common denominator for microwave modeling and optical modeling of vegetation canopies. Plant water content determines the dielectric properties influencing microwave backscatter and the degree of absorption/reflectance in the infrared and is a function of the amount of live plant matter, the biophysical parameter for which information is sought through these techniques.
- (2) An experiment designed to provide a common data set to all optical and microwave investigators where both field measurements and remotely sensed measurements in all wavelength regimes are acquired simultaneously would be highly desirable at this stage of the research program.

- (3) Based on the progress of the investigations to date, it is an appropriate time to direct research towards the development of techniques for combining information learned about the target and the atmosphere from the separate wavelength regions. We should also advance our models from single plant canopy studies to field canopy studies to improve the characterization of scene radiation.
- (4) Future program initiatives should encourage coordination of interests between the scene radiation (SRAEC) group and the mathematical pattern recognition (MPRIA) group to foster complementary research. For example, image representation techniques developed independently by the MPRIA effort should now be tested for their use in validating canopy radiance models developed by the SRAEC effort and applied within the context of an image scene.

The workshop was an extremely effective mechanism for stimulating research interests and sustaining a thread of commonality among the diverse investigation objectives. A list of workshop participants is enclosed. A workshop proceedings will be published within a month.

*M. Kristine Butera*

M. Kristine Butera

Enclosure

cc:  
EE/Tilford  
EE/Arnold  
EE/Hogg  
EE/Settle  
EE/Trichel  
EE/Tuyahov  
EE/Agarwal  
EE/Watson  
GSFC/923/Murphy  
GSFC/923/Deering  
JSC/SG3/Heydorn

**END**

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**JUN 19 1984**

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